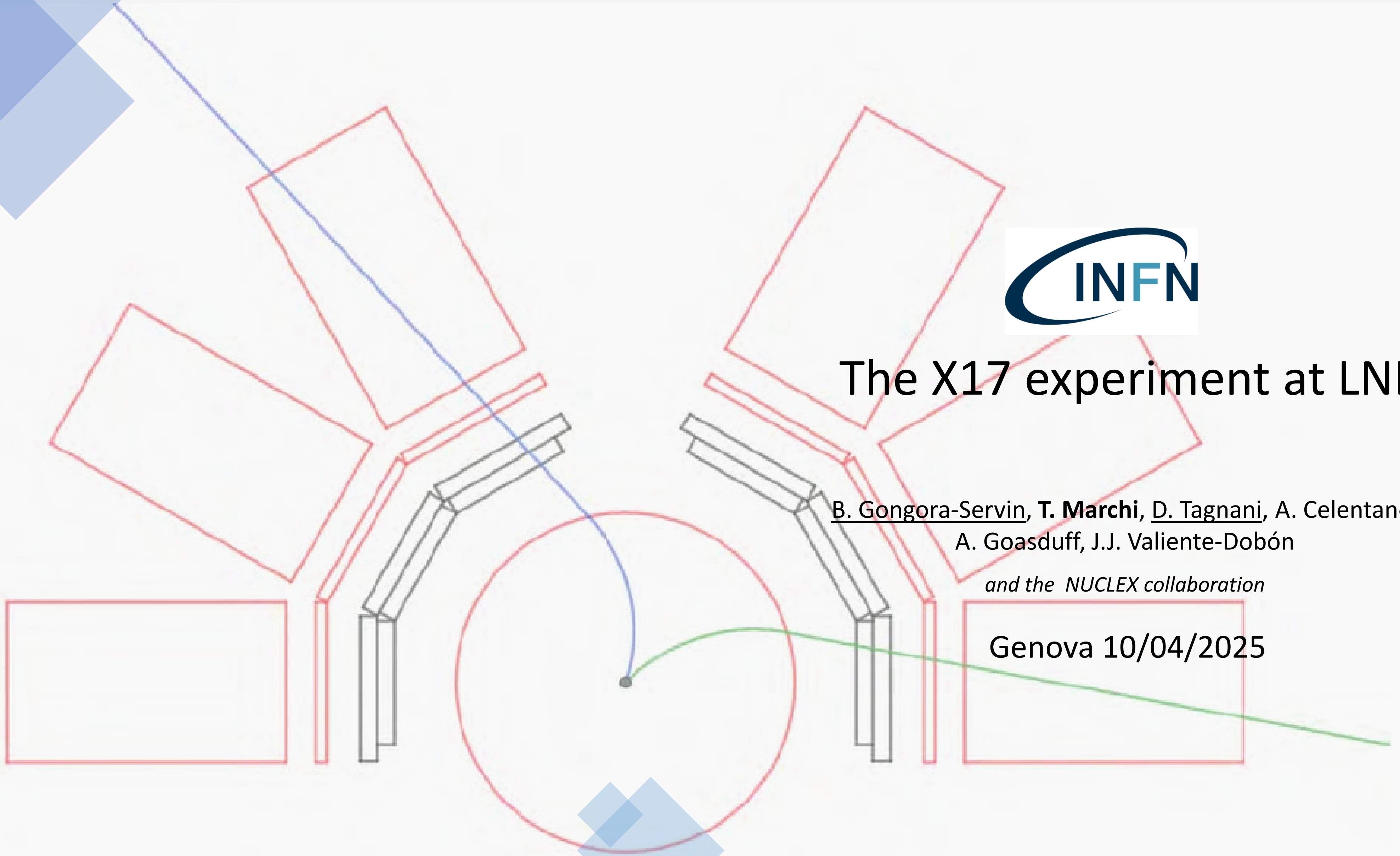


The X17 experiment at LNL

<u>B. Gongora-Servin</u>, **T. Marchi**, <u>D. Tagnani</u>, A. Celentano, A. Goasduff, J.J. Valiente-Dobón

and the NUCLEX collaboration

Genova 10/04/2025

Emission of e^+e^- pairs coupled to the Nuclear Field.
It must be disentangled from pair production due to high energy gamma rays.

Theory is well established since Rose's work:

- M.E. Rose, Phys Rev 76, 678 (1949);
- E.K. Warburton, Phys Rev 133, 6B (1964)
- P. Schlüter et al, Phys Rep 75, 327 (1981)
- P. Schlüter et al, At Data and Nucl Data Tab 24, 509 (1979)

It is possible to compute:

Pair Conversion Coefficients (PCC)

Electron-positron angular correlations

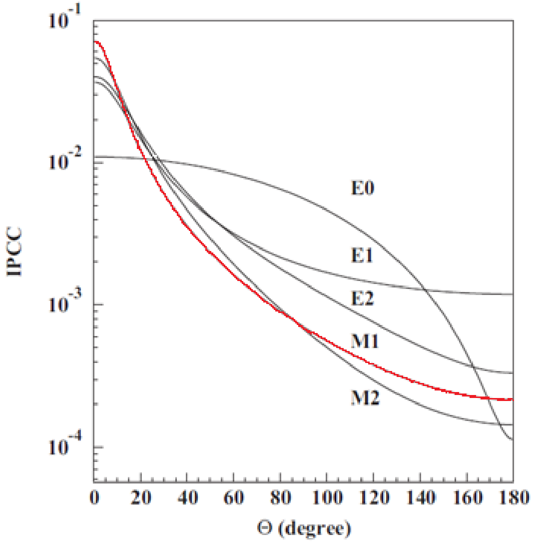
- Possible only for ΔE>1.022 MeV
- Competes with gamma emission (typical cross section ratio is 10^{-3})
- Allowed for monopole transitions
- Allows to directly probe transition properties

Detecting "high energy" e+e- pairs (sharing 10-20 MeV of kinetic energy) emitted in an environment dominated by gamma-rays poses an experimental challenge.

Outline

- Motivation and interest on the "X17 case"
- Aipac8Be: a new setup at LNL for IPC studies
- Preliminary experimental results for $^8Be^*$ decay

Motivation: renewed interest on IPC.



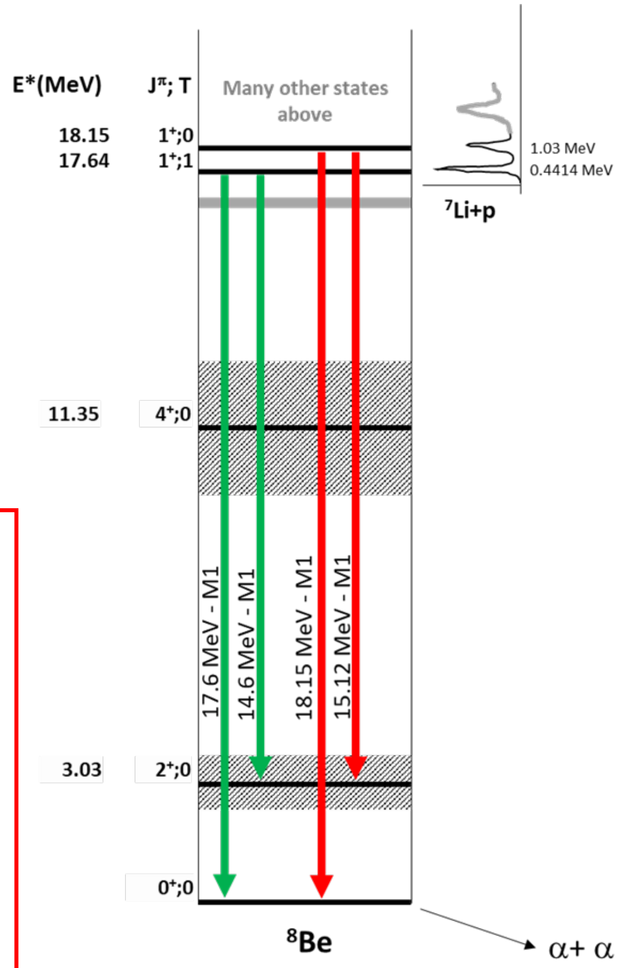
A. J. Krasznahorkay et al. (2016)

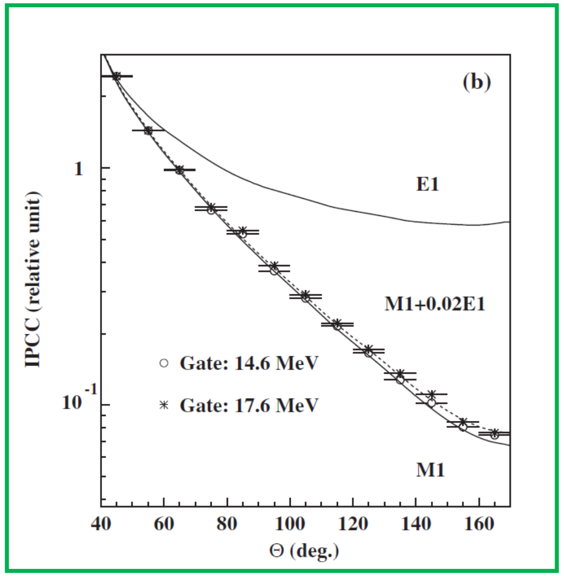
Beam: protons in the 0.5 -1.2 MeV range

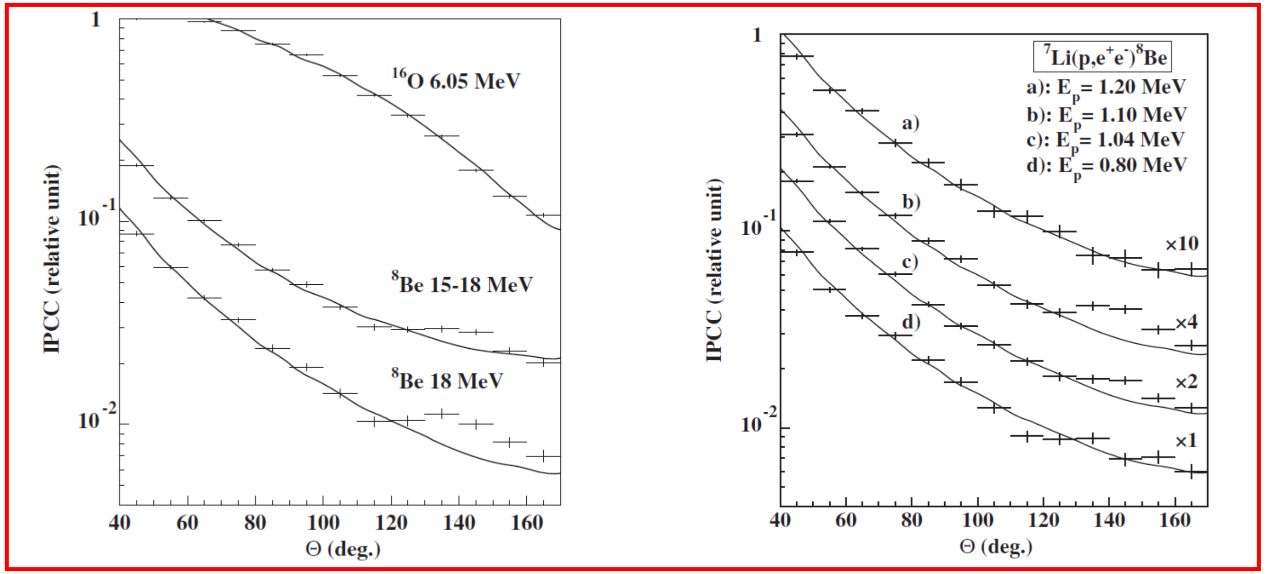
Targets: LiF_2, LiO_2.

The reaction: ^{7}Li(p,e$^+$e$^-$)^{8}Be allows to selectively populate the 17.64 MeV and 18.15 MeV resonances.

The considered transitions are M1 type. Isospin is assigned in analogy to isobaric nuclei -> two iso-scalar and two iso-vector transitions.







[A. J. Krasznahorkay et al, Phys Rev Lett 116, 042501 (2016)]

Motivation: curiosity for the “X17” case.

PRL **116,** 042501 (2016) PHYSICAL REVIEW LETTERS week ending 29 JANUARY 2016

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

A. J. Krasznahorkay,* M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B. M. Nyakó, L. Stuhl, J. Timár,

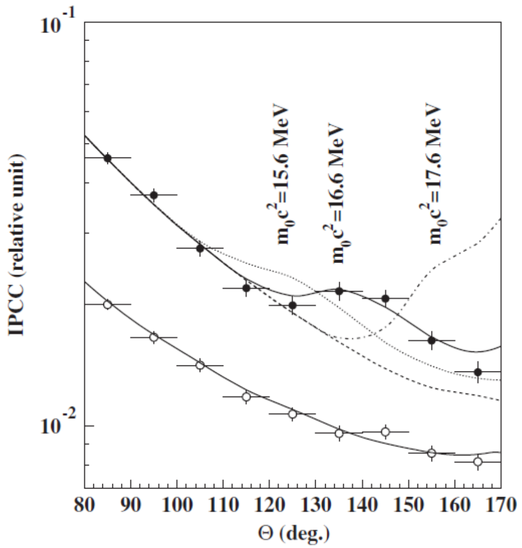


FIG. 4. Experimental angular e^+e^- pair correlations measured in the ^{7}Li(p, e^+e^-) reaction at $E_p = 1.10$ MeV with $-0.5 \le y \le 0.5$ (closed circles) and $|y| \ge 0.5$ (open circles). The results of simulations of boson decay pairs added to those of IPC pairs are shown for different boson masses as described in the text.

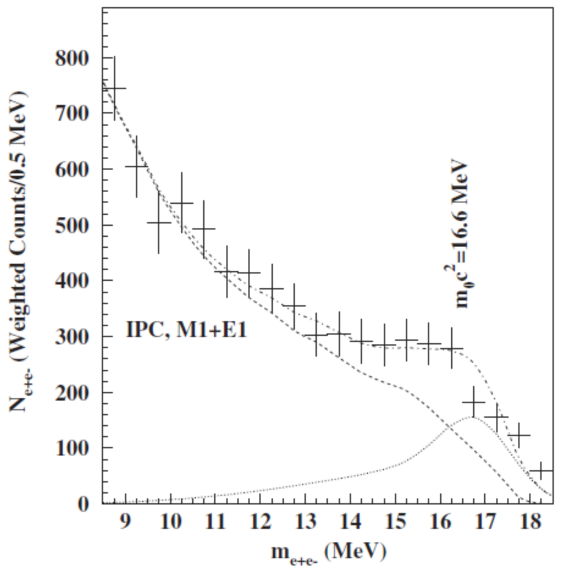


FIG. 5. Invariant mass distribution derived for the 18.15 MeV transition in ^{8}Be.

The deviation between the experimental and theoretical angular correlations is significant and can be described by assuming the creation and subsequent decay of a $J^\pi=1^+$ boson with $m_0c^2=16.70\pm0.35(stat)\pm0.5(syst)$ MeV/c^2. The branching ratio of the e^+e^- decay of such a boson to the γ-decay of the 18.15 MeV level of ^{8}Be was found to be 5.8×10^{-6} for the best fit.

Such a boson might be a good candidate for the relatively light $U(1)_d$ gauge boson [4], or the light mediator of the secluded WIMP dark matter scenario [5] or the dark Z (Zd) suggested for explaining the muon anomalous magnetic moment [7].

Literature on IPC anomaly.

F.W. N. de Boer et al, Phys Lett B 388, 235 (1996)
F.W. N. de Boer et al, J. Phys G: Nucl Part Phys 23, L85 (1997)
F.W. N. de Boer et al, J Phys G: Nucl Part Phys 27, L29 (2001)
And several others.

Results of two dedicated experiments are reported yielding further indications for an anomaly at 9 MeV/c2 in the angular correlation of IPC. The first experiment (8Be) shows a deviation from IPC at large correlation angles presumably due to the same anomaly in the transition to the first excited state. The second experiment (12C) shows a relatively large anomaly at 9 MeV/c2, albeit with limited statistics. Both results are compatible with an X-boson scenario where the boson–nucleon coupling strength is proportional to the isoscalar strength in the M1 transition. Exploiting isospin structure as a guideline, further high statistics experiments are needed to establish the nature of the anomaly.

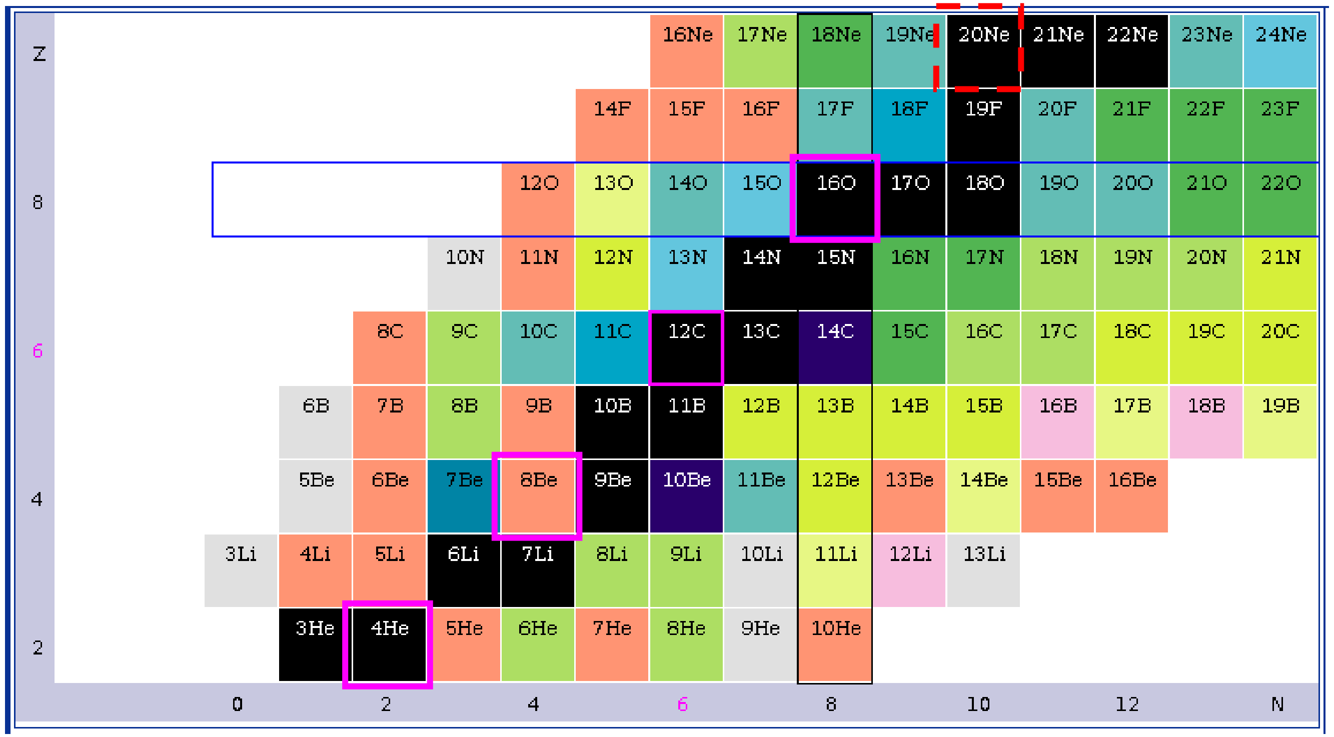
Table 1. Experimental results relevant for the search of anomalous e^+e^- production in nuclear transitions with respect to IPC, in the invariant mass range from 5 to 15 MeV/c^2. Listed are the nucleus, the quantum numbers, the energy (E) and character (E1, M1) of the transition, the derived boson emission branching ratio (B_X) with respect to γ emission, the boson decay width (Γ_X), the isospin dependent effective coupling strength (α_X), relative to $\tilde{\alpha} = 1.7 \times 10^{-6}$ (the axion–nucleon coupling strength), the invariant mass m_X and the literature references. Values for B_X and Γ_X have been derived at 95% CL.

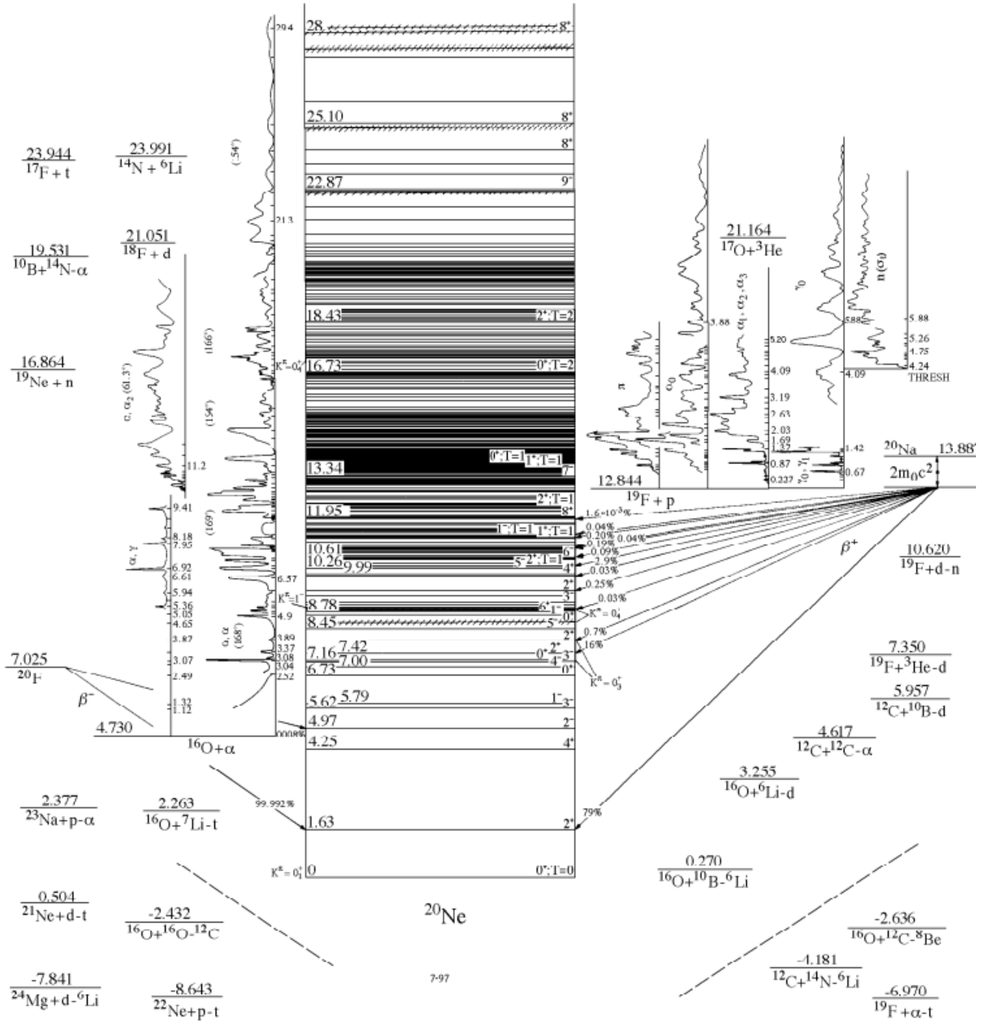
^AZ	I^π	T	E MeV	B_X	Γ_X meV	α_X 1.7×10^{-6}	m_X MeV/c^2	Reference
^{20}Ne	1^-	1	17.8 E1	$\leqslant 1.3 \times 10^{-4}$	$\leqslant 3$	$\leqslant 1.8$		[20]
			16.2 E1					
^{12}C	1^-	1	17.2 E1	$\leqslant 2.3 \times 10^{-5}$	$\leqslant 1$	$\leqslant 0.3$		[1]
	2^-	1	12.3 E1					
^{12}C	1^+	0	12.7 M1	$(1.6 \pm 0.7) \times 10^{-3}$	0.55 ± 0.24	38 ± 17	9.2 ± 1.0	[6]
^{12}C	1^+	1	15.1 M1	$\leqslant 4.6 \times 10^{-5}$	$\leqslant 1.7$	$\leqslant 0.9$		[6]
^{12}C			114 M1	$\leqslant 9.8 \times 10^{-5}$	$\leqslant 8$	$\leqslant 0.8$		[8, 23]
^{8}Be	1^+	1, 0	17.6 M1	$(11.4 \pm 3.4) \times 10^{-5}$	1.9 ± 0.4	1.5 ± 0.4	9 ± 1	[1]
			14.6 M1					
^{4}He	0^-	0	21.0 e^+e^-		74 ± 30	32 ± 12	8 ± 2	[15, 5]

Table 1. Experimental results for anomalous e^+e^--emission interpreted in the light of a short-lived 9 MeV/c^2 X-boson in six M1 transitions and an M0 transition. Listed are the nucleus, the energy and the width of the resonance E_R and Γ_R, the (iso)spin-parity quantum numbers, the transition energy E_γ, the X-branching ratio B_X with respect to γ-emission, the X-decay width Γ_X, the coupling strength α_X relative to $\tilde{\alpha} = 1.7 \times 10^{-6}$ (the axion–nucleon coupling strength), the invariant mass m_X, and the references. Values for B_X and m_X have been derived at 95% CL.

^AZ	E_R (MeV)	Γ_R (eV)	I^π, T	E_γ (MeV)	B_X	Γ_X (meV)	α_X 1.7×10^{-6}	m_X (MeV/c^2)	Refs
^{12}C	12.71	18.1	$1^+, 0$	12.71	$(7 \pm 3) \times 10^{-4}$	0.24 ± 0.11	18 ± 7	9.0 ± 1.0	Present
				12.71	$(1.6 \pm 0.7) \times 10^{-3}$	0.56 ± 0.25	38 ± 17	9.2 ± 1.0	[5–7]
	15.11	43.6	$1^+, 1$	15.11	$\leqslant 4.6 \times 10^{-5}$	$\leqslant 1.8$	$\leqslant 0.9$	—	[5–7]
^{8}Be	17.64	10.7×10^3	$1^+, 1$	17.64	$(1.1 \pm 0.3) \times 10^{-4}$	1.9 ± 0.4	1.5 ± 0.4	9 ± 1	[2–4]
				14.64	$(8.5 \pm 2.6) \times 10^{-5}$	0.7 ± 0.2	1.5 ± 0.4	9 ± 1	[2–4]
	18.15	138×10^3	$1^+, 0$	18.15	$\leqslant 4.1 \times 10^{-4}$	$\leqslant 1.2$	$\leqslant 5.7$	—	Present
				15.15	$(5.8 \pm 2.2) \times 10^{-4}$	2.2 ± 0.8	10.5 ± 4.5	9.5 ± 1.2	Present
^{4}He	21.0	850×10^3	$0^-, 0$	M0	$0^- \to 0^+, e^+e^-$	74 ± 30	32 ± 12	8 ± 2	[5–7]

Is alpha-clustering hiding behind the scene?

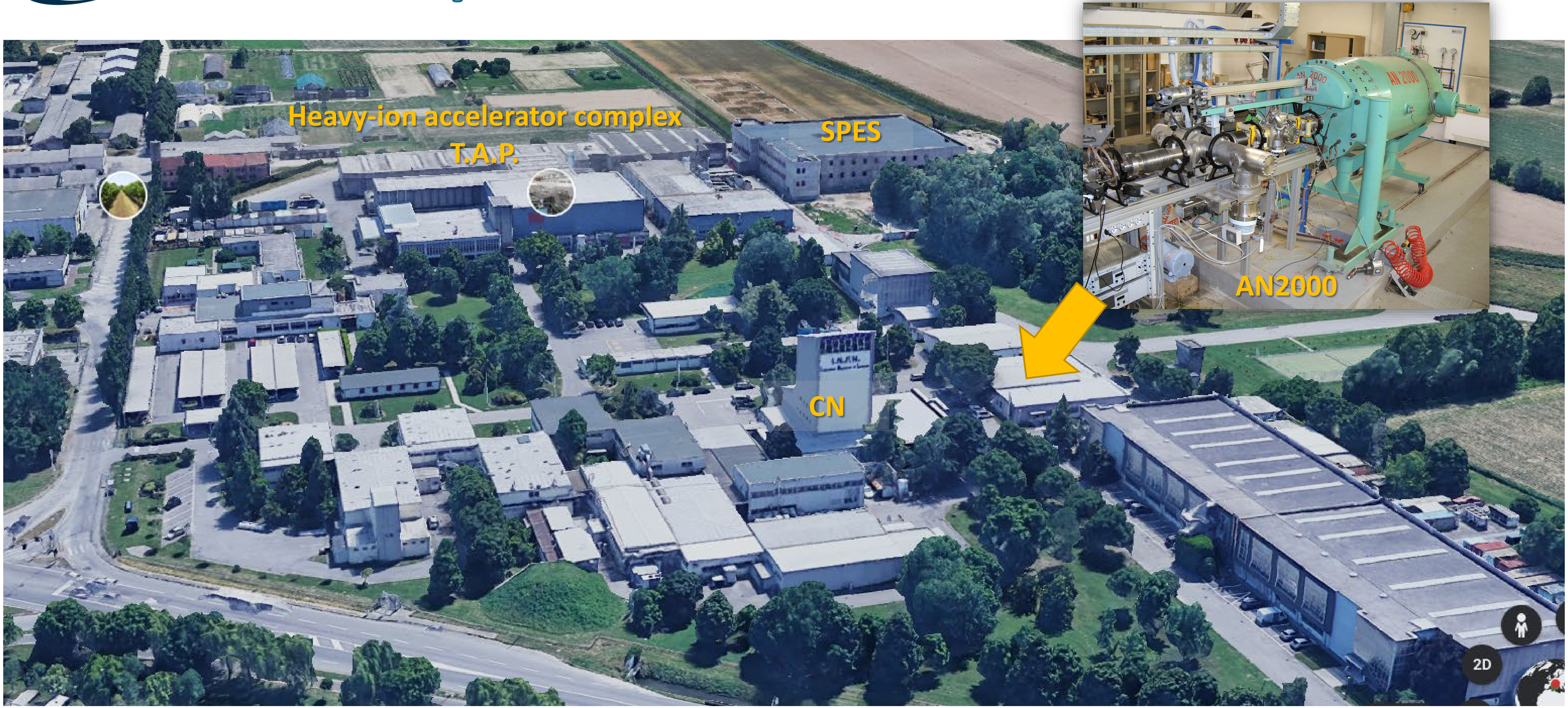




Can we provide independent data?

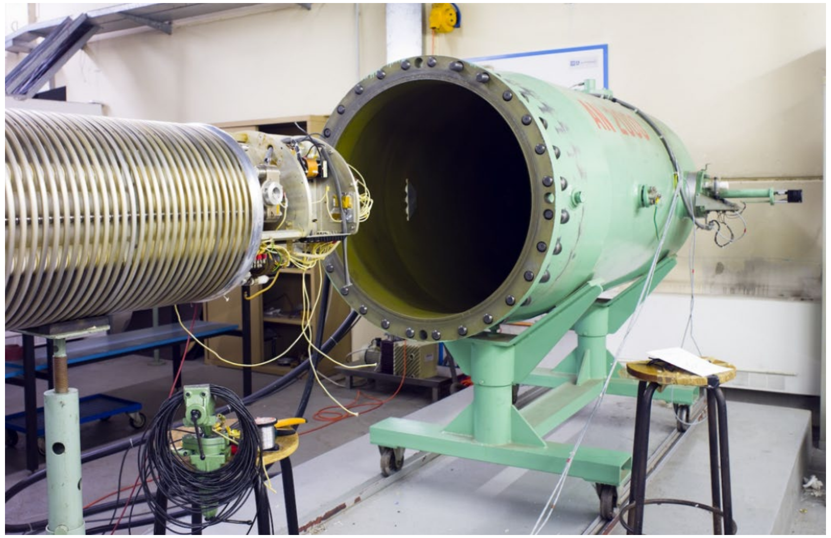
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Legnaro

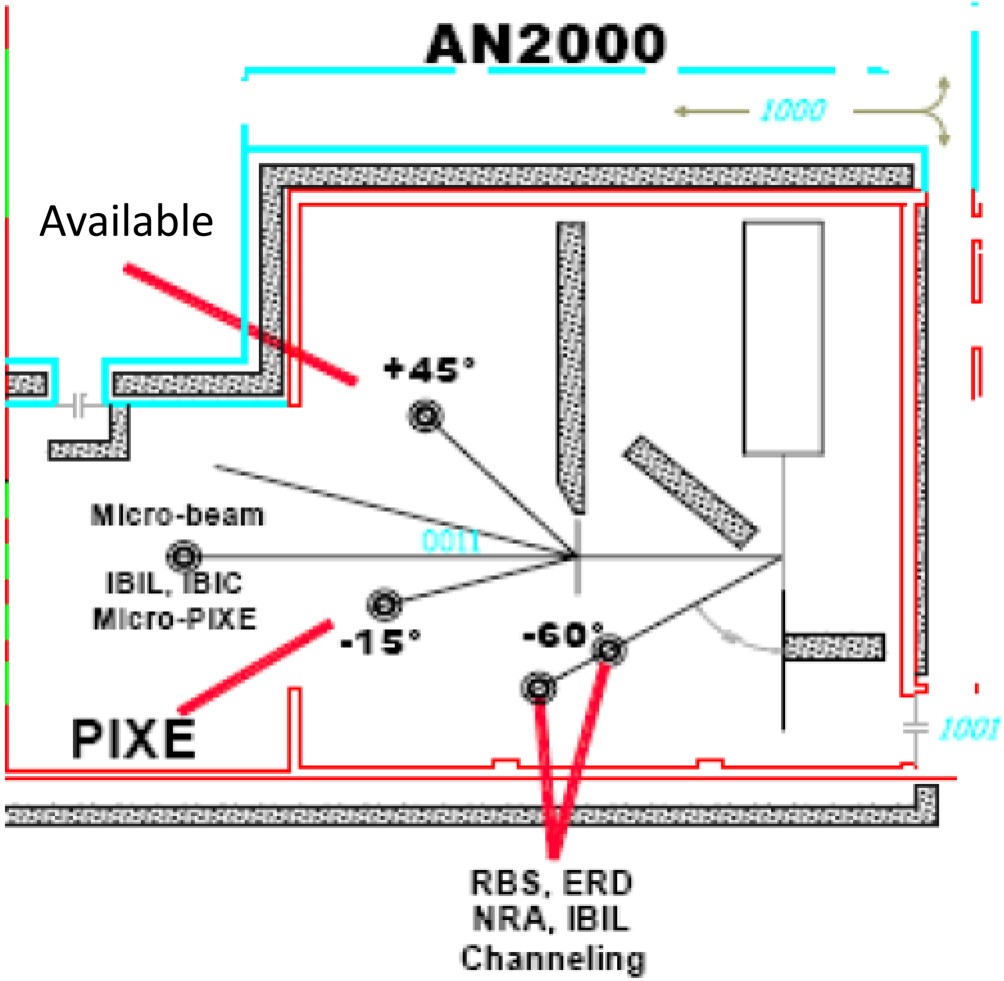
We do have a useful facility



AN2000 by High Voltage Engineering
Operational since 1971.

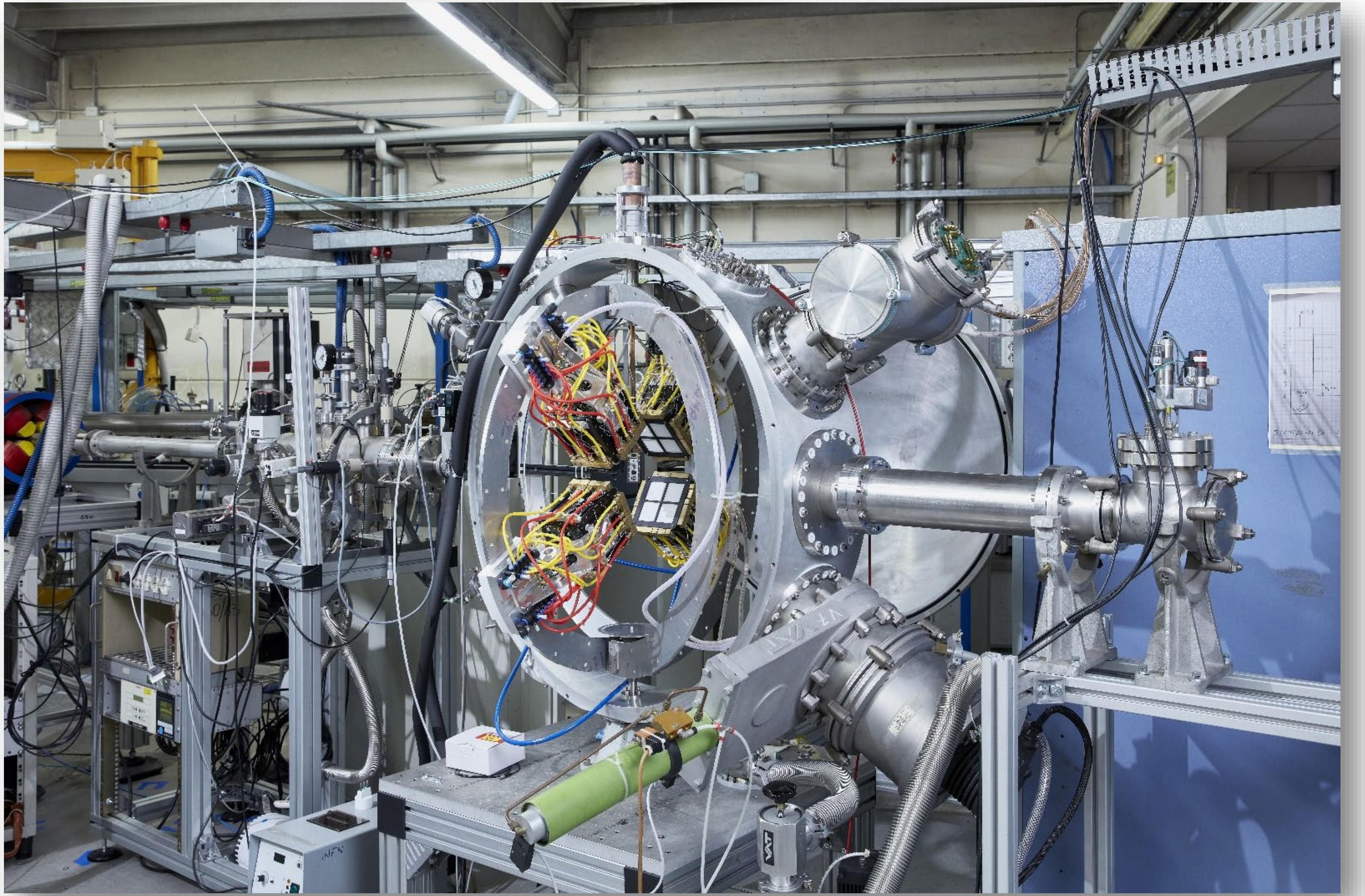
Ions: $^{1(2)}$H+, $^{3\text{-}4}$He+.
Maximum Terminal Voltage: 2.5 MV, single stage (belt).
Beam current: up to 1 μA.



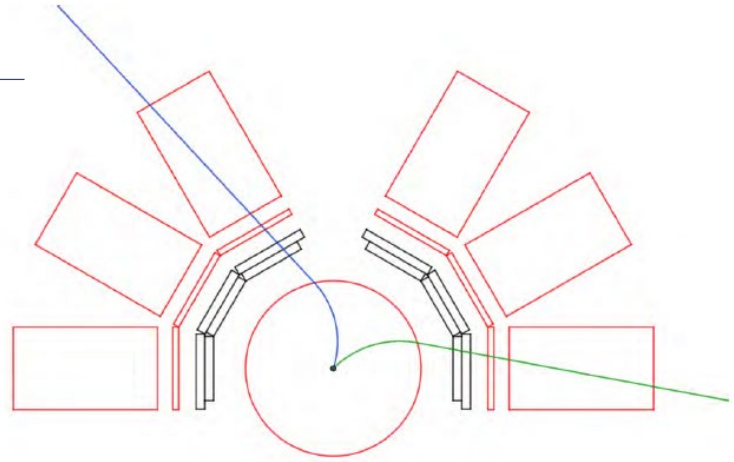


[https://www.lnl.infn.it/index.php/en/home-3/9-uncategorised/235-featuresbeams]

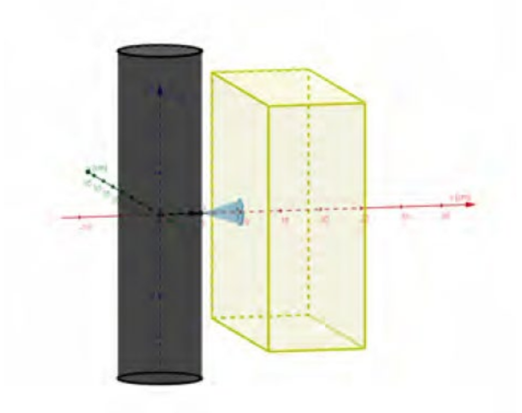
The Aipac8Be setup at AN2000



Design of a new IPC setup: can we improve sensitivity?



- Positrons are not discriminated from electrons. -> Future coupling to magnetic field.
- Target composition and stability are critical.
- Solid angle coverage is limited to theta=90°.
- Can we improve energy resolution?
- **Angular resolution is limited by straggling:**



Spessore [mm]	Energie [MeV]		
	10	15	20
0.7	8°	5.5°	3.5°
1	9°	6.8°	4.5°
1.5	11°	8°	5.5°

therefore
detectors must be placed inside the scattering chamber

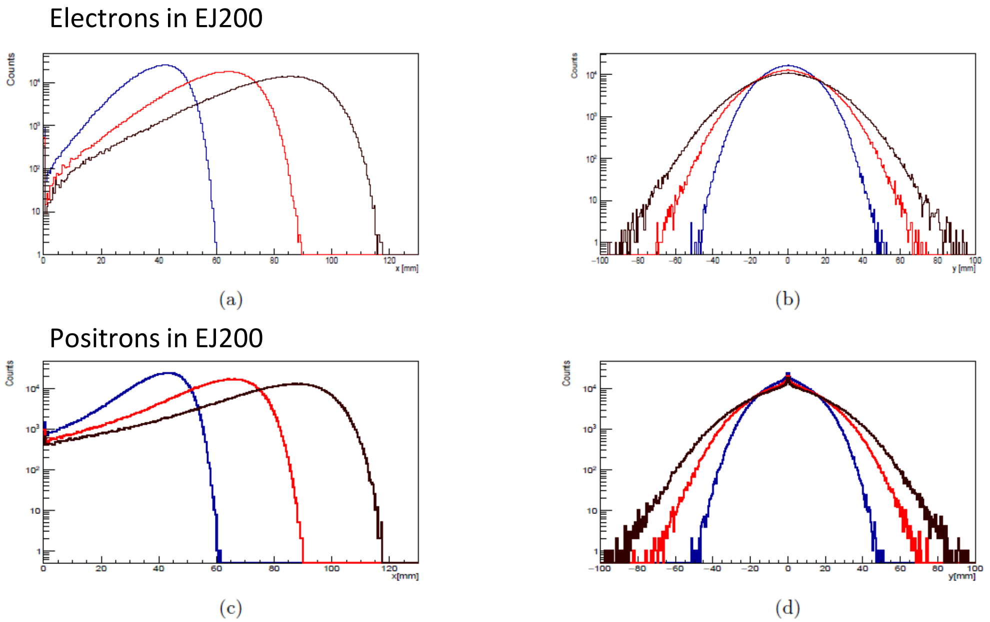


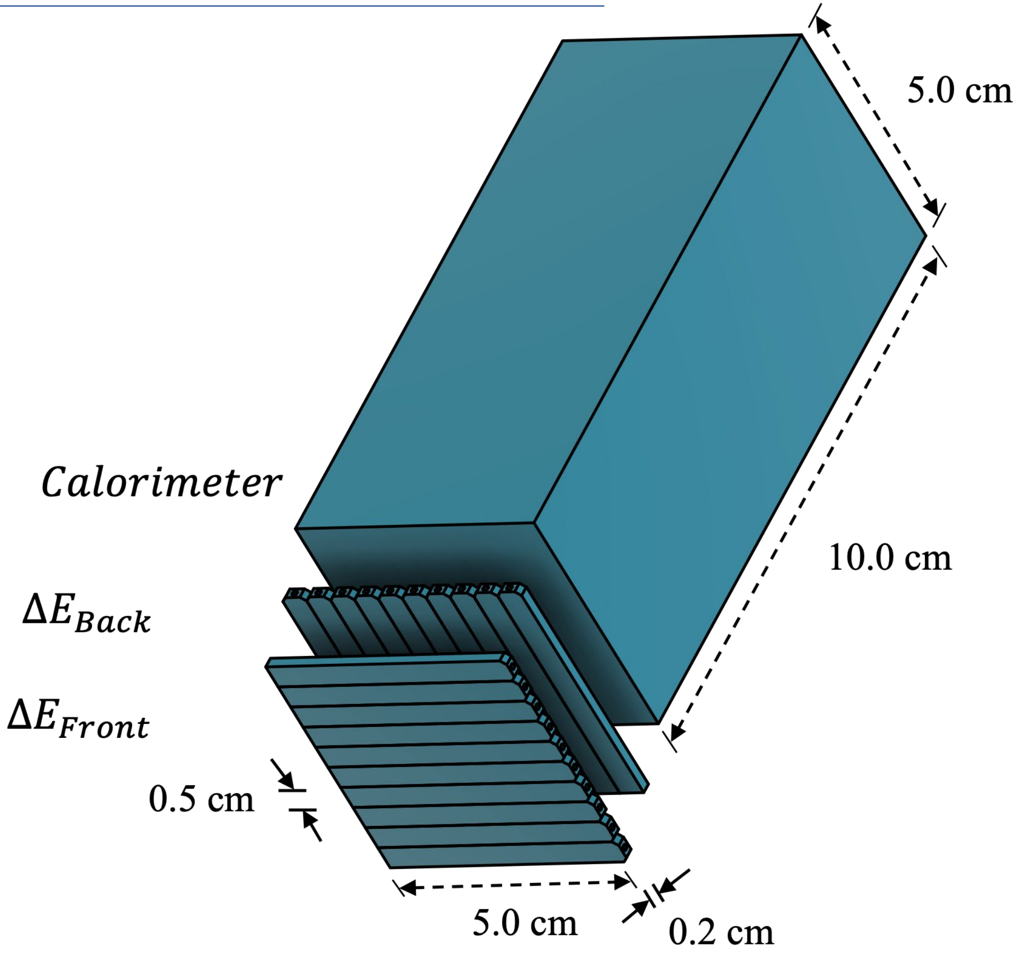
Figure 3.1: Absorption position of electrons (a, b) and positrons (c, d), with a logarithmic scale on the counts, at different emission energies: 10 MeV (blue), 15 MeV (red), 20 MeV (brown).

[R. Bolzonella, Preparazione di un esperimento per la misura di coppie e+e- nel decadimento del 8Be*, Università di Padova (2019)]

- Improve angular resolution by reducing material budget.
- Improve angular coverage and measure out-of-plane correlations
- Improve confidence on target composition.

- Allow future coupling with a magnetic field.

- Focus on ^{8}Be and, possibly, ^{12}C cases.

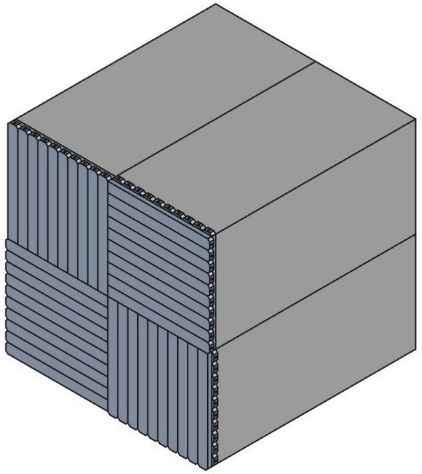


Single Telescope
Modular detector

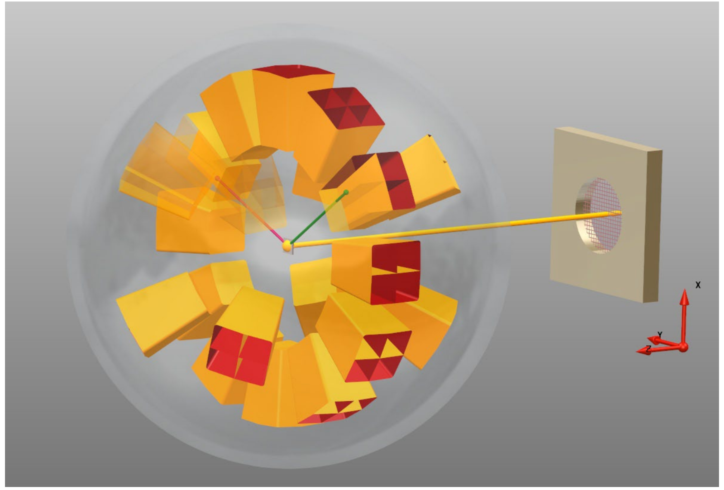
- Improve angular resolution by reducing material budget.
- Improve angular coverage and measure out-of-plane correlations
- Improve confidence on target composition.

- Allow future coupling with a magnetic field.

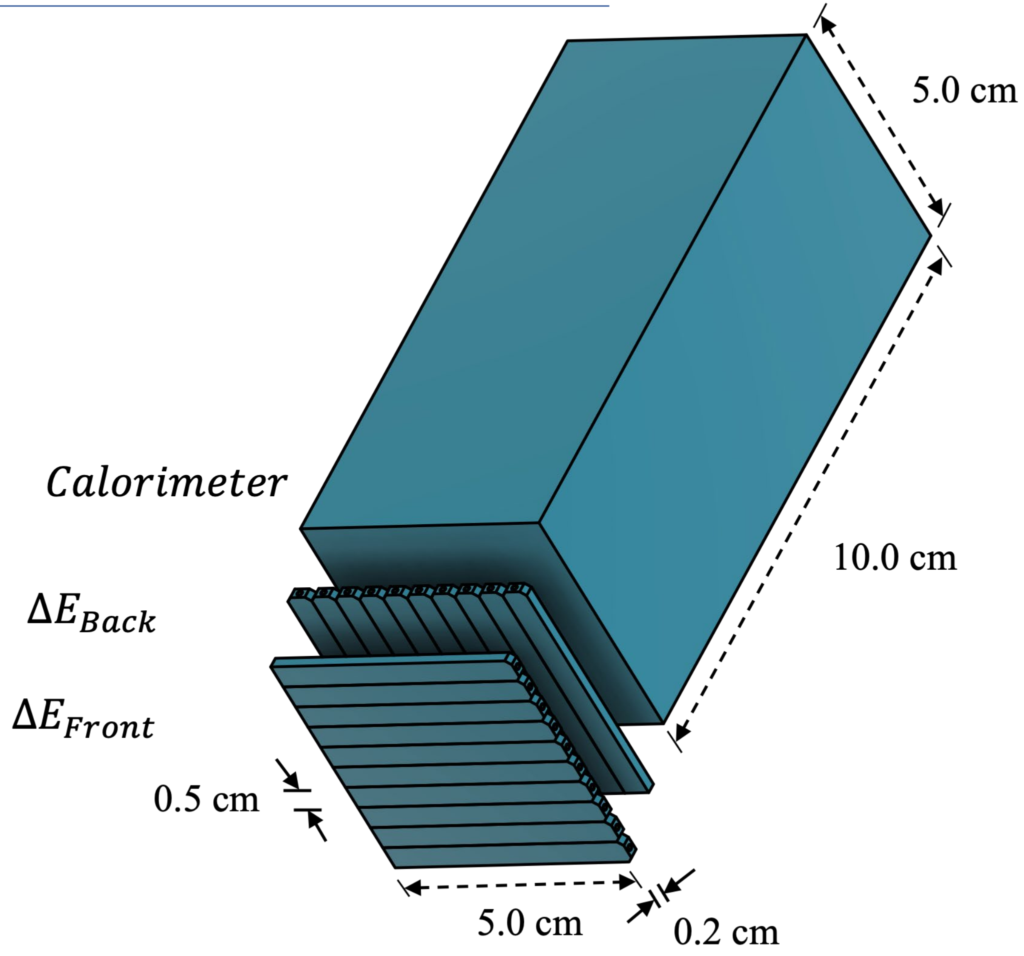
- Focus on ^{8}Be and, possibly, ^{12}C cases.



Clover
Four Telescope Cluster

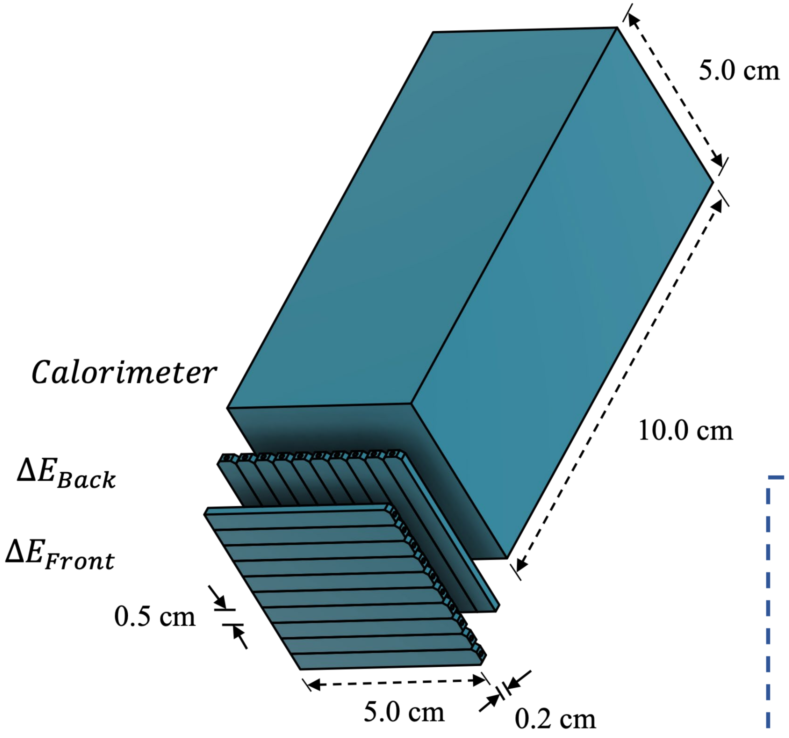


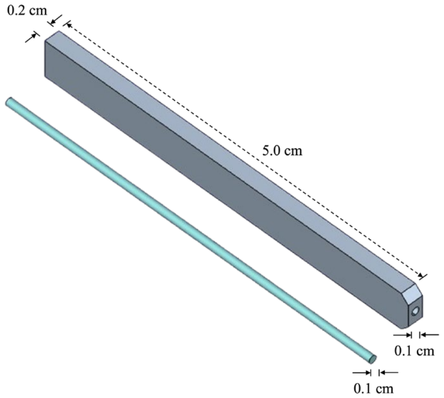
Array of clovers

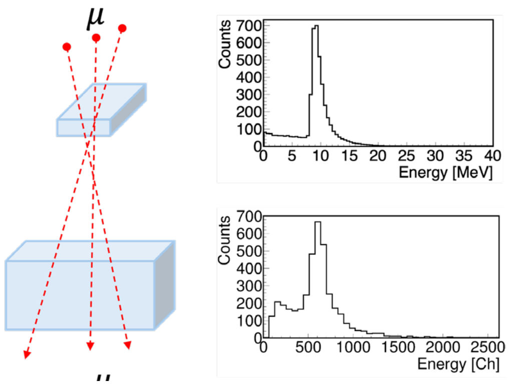


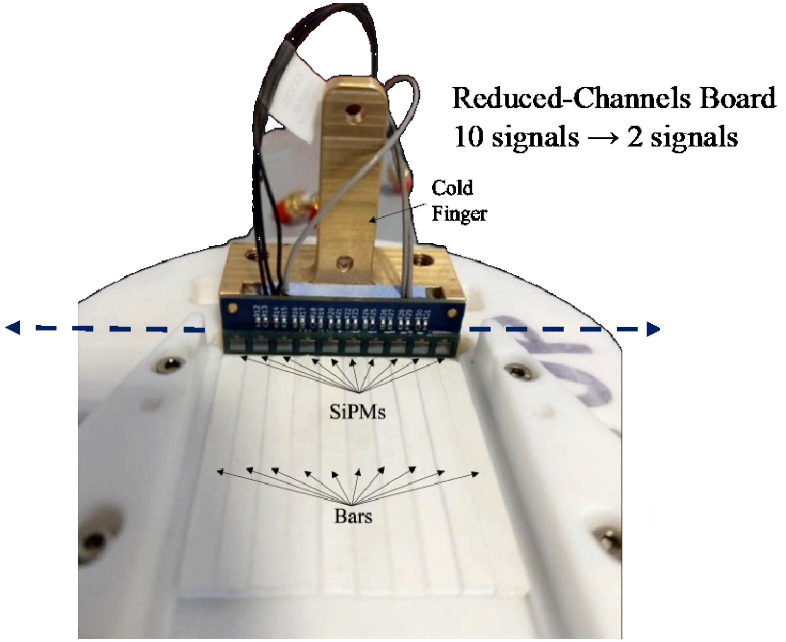
Single Telescope
Modular detector

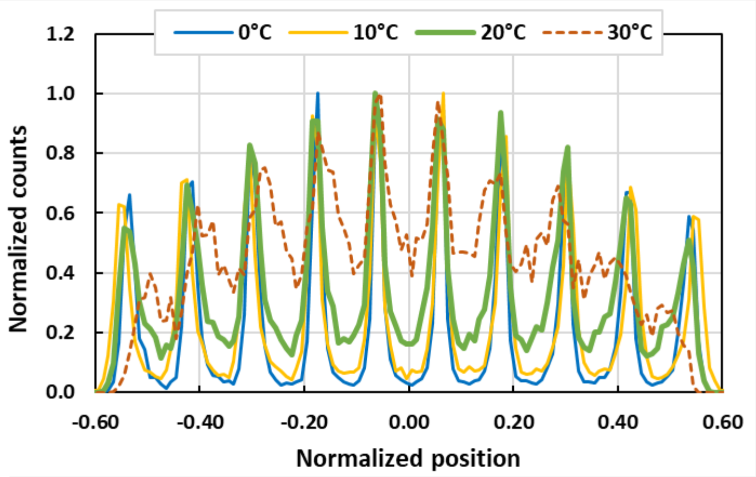
Light readout







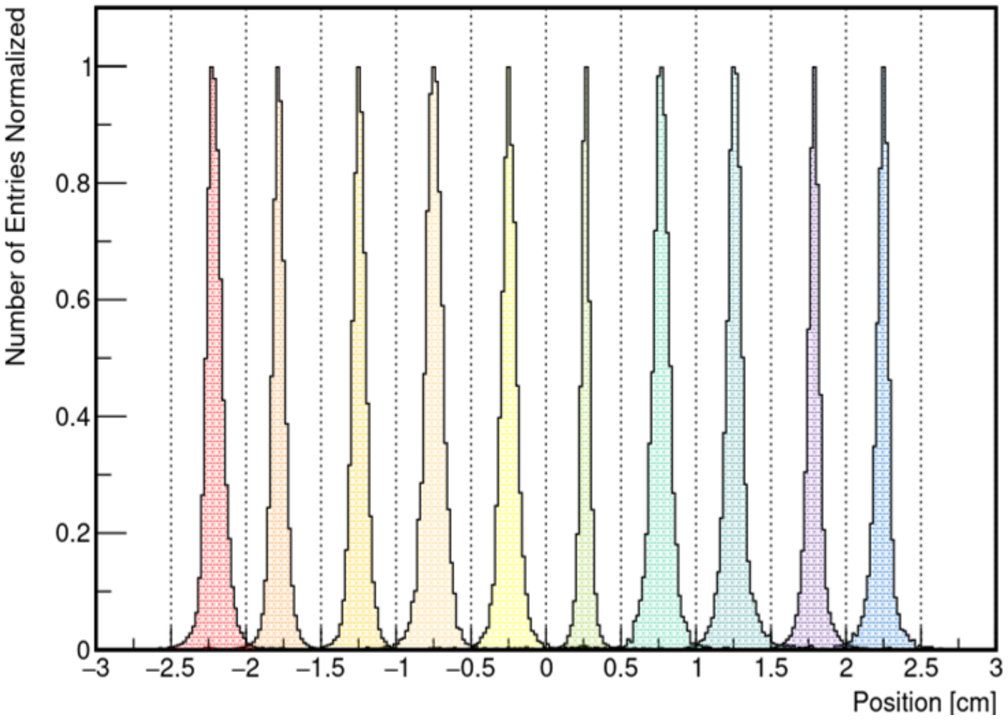




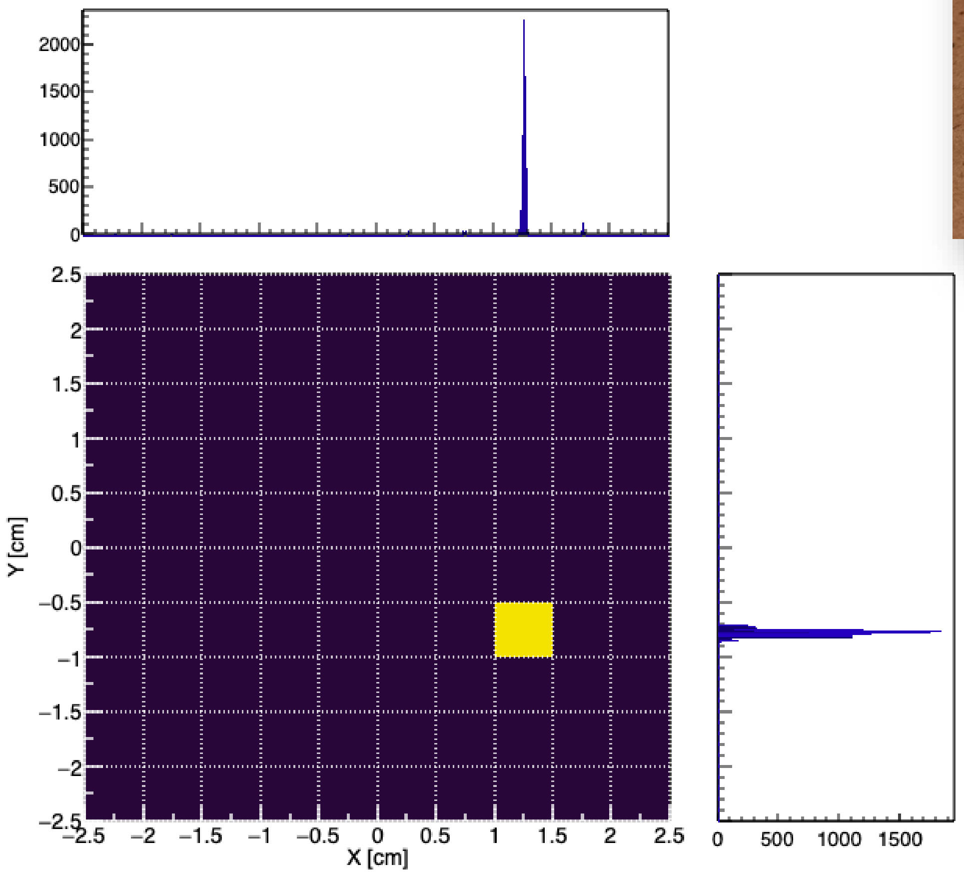
Best performance at 0° temperature

F. Acerbi et al. IEEE Trans. on Nucl. Sci, Vol. 71, No. 12, 2024

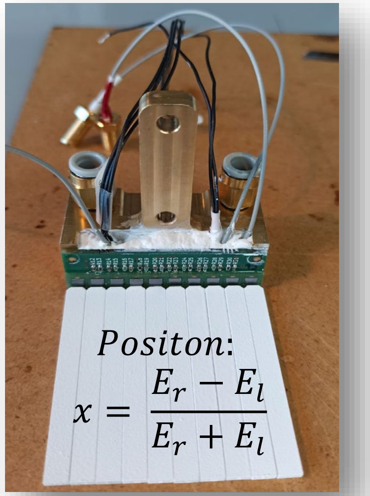
Position reconstruction



Position Measurement @ 0°C (^{241}Am source)



Position Measurement @ 0°C (^{90}Sr/ ^{90}Y source)

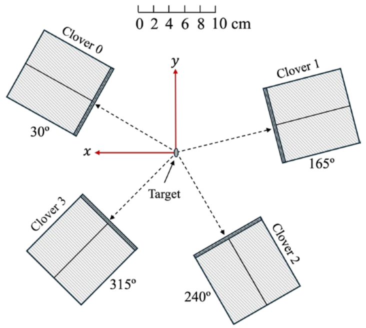


$$x = \frac{E_r - E_l}{E_r + E_l}$$

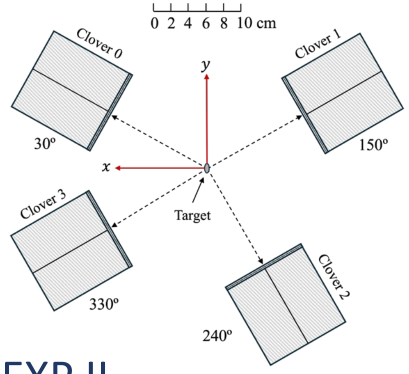
Setup @ AN2000 (30° beamline), LNL-INFN

- Cooling system at 0°C.
- Block on top of the target ladder to cool the target frame.
- PT100 sensor to monitor the temperature in the detectors, target frame, and chamber
- **Thermal camera** to monitor the temperature in the target on the beam spot
- System of two cameras for **visual check of the target integrity**

Experiment	Number of Clovers	Angles [∘]	Time [hrs]
Commissioning	2	30, 315	155
Experiment I	4	30, 165, 240, 315	236
Experiment II	4	30, 150, 240, 330	392

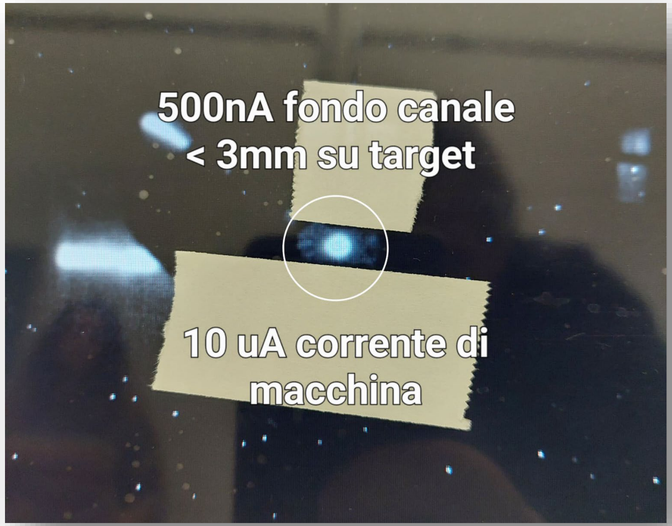


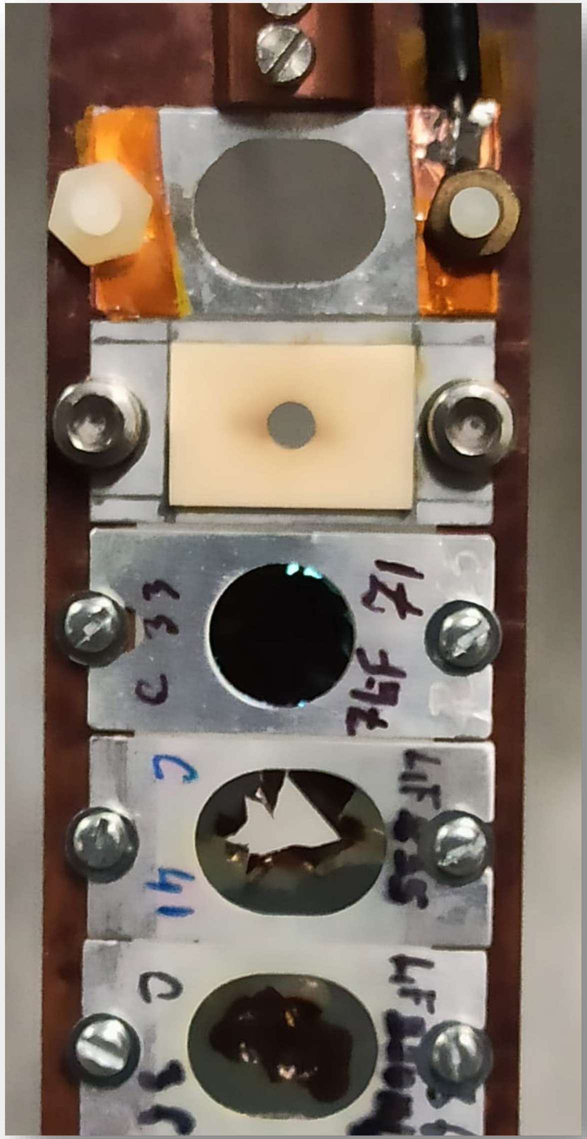
EXP I

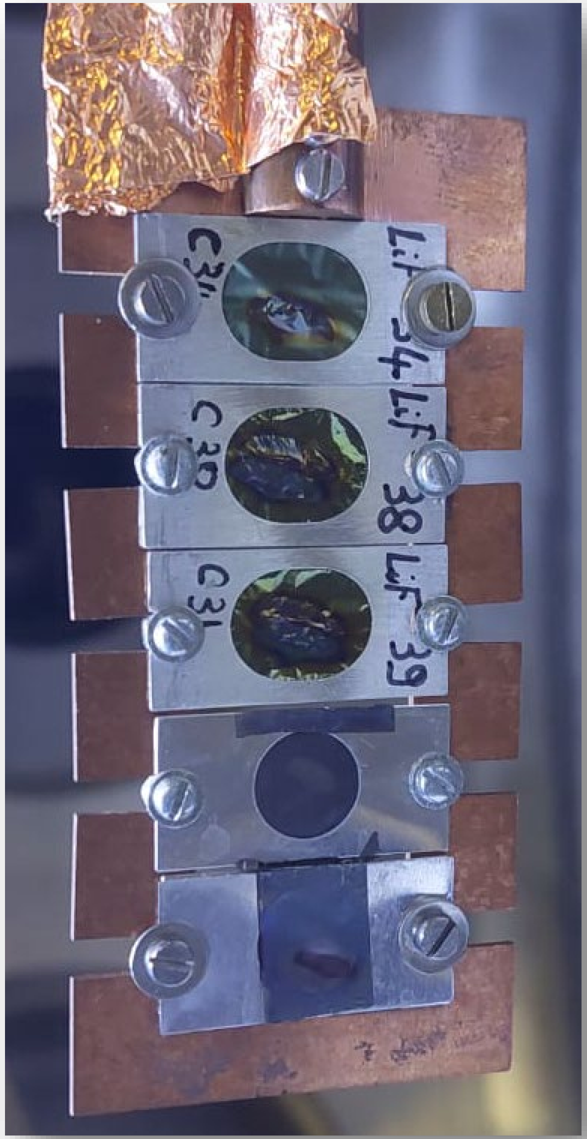


EXP II

Beam and targets







- H beam at 0.441 and 1.03 MeV (up to 600 nA)
- LiF on Cu backing
- LiF on C backing
- LiF with Au coating

Sampling the excitation function

The $S(E)$ factor of $^7Li(p,\gamma)^8Be$ and consequences for $S(E)$ extrapolation in $^7Be(p,\gamma_0)^8B$

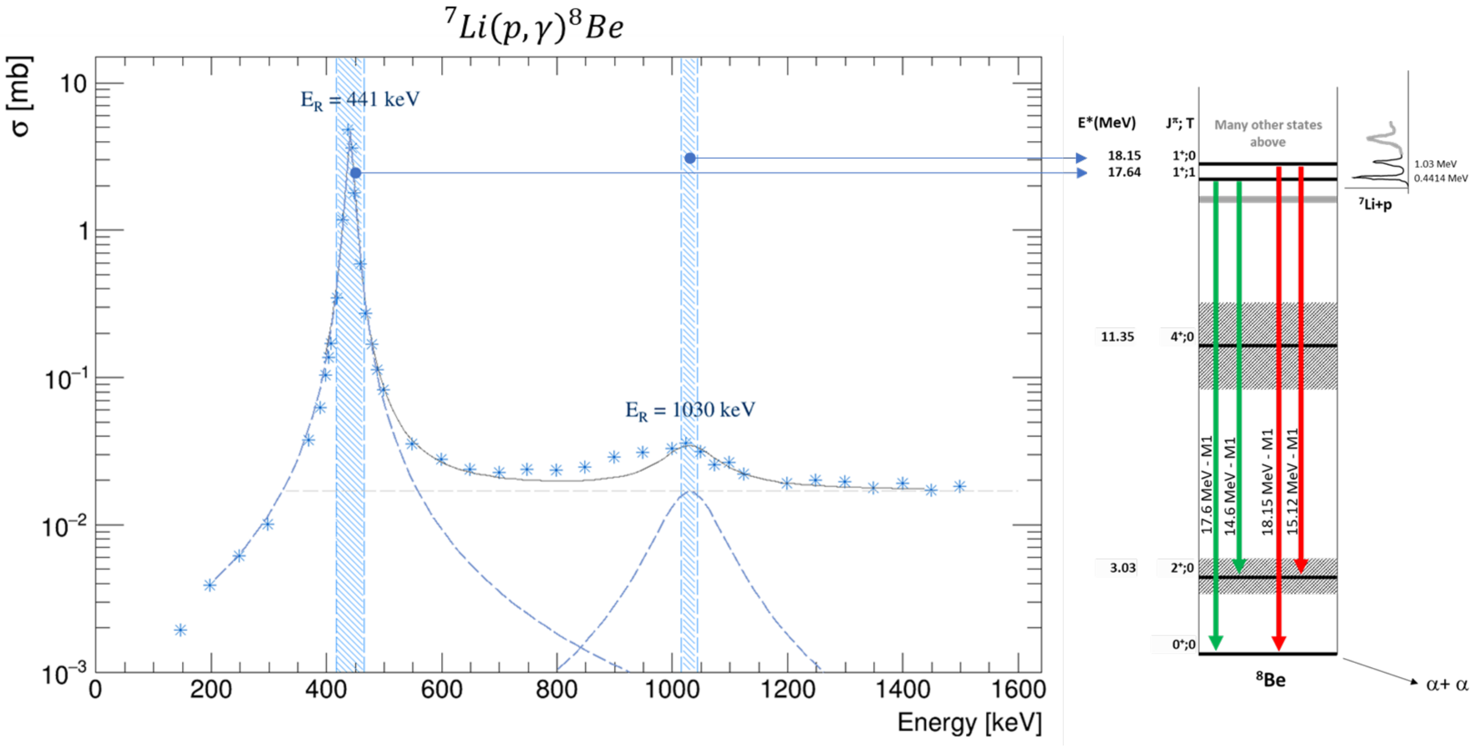
D. Zahnow[1], C. Angulo[2], C. Rolfs[3], S. Schmidt[1], W.H. Schulte[1], E. Somorjai[3]

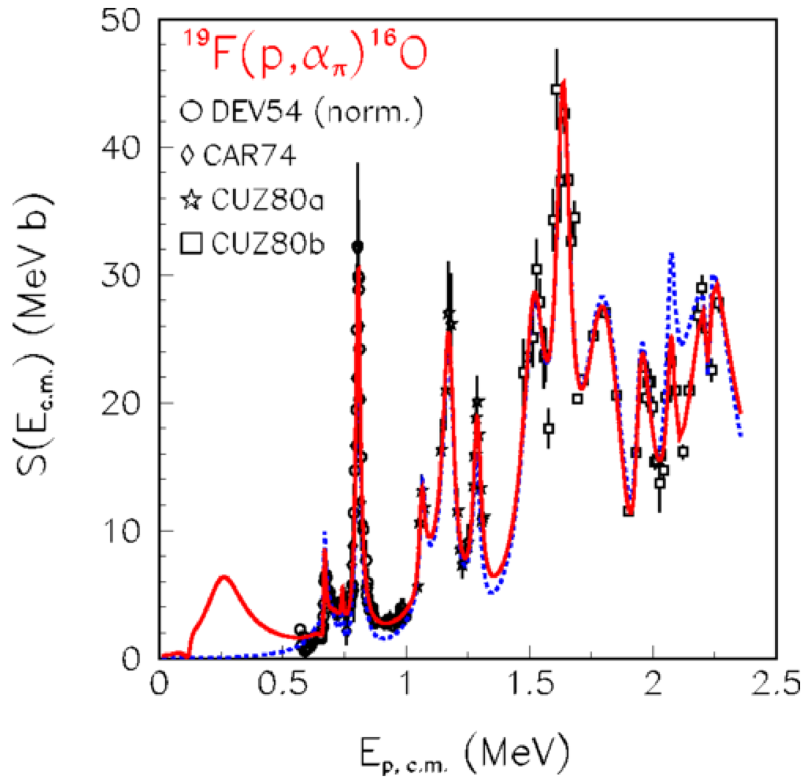
[1]Institut für Physik mit Ionenstrahlen, Ruhr-Universität Bochum, Universitätstrasse 150, D-44780 Bochum, Germany
[2]CSNSM, Orsay, France
[3]ATOMKI, Debrecen, Hungary

Received: 30 August 1994/Revised version: 19 October 1994

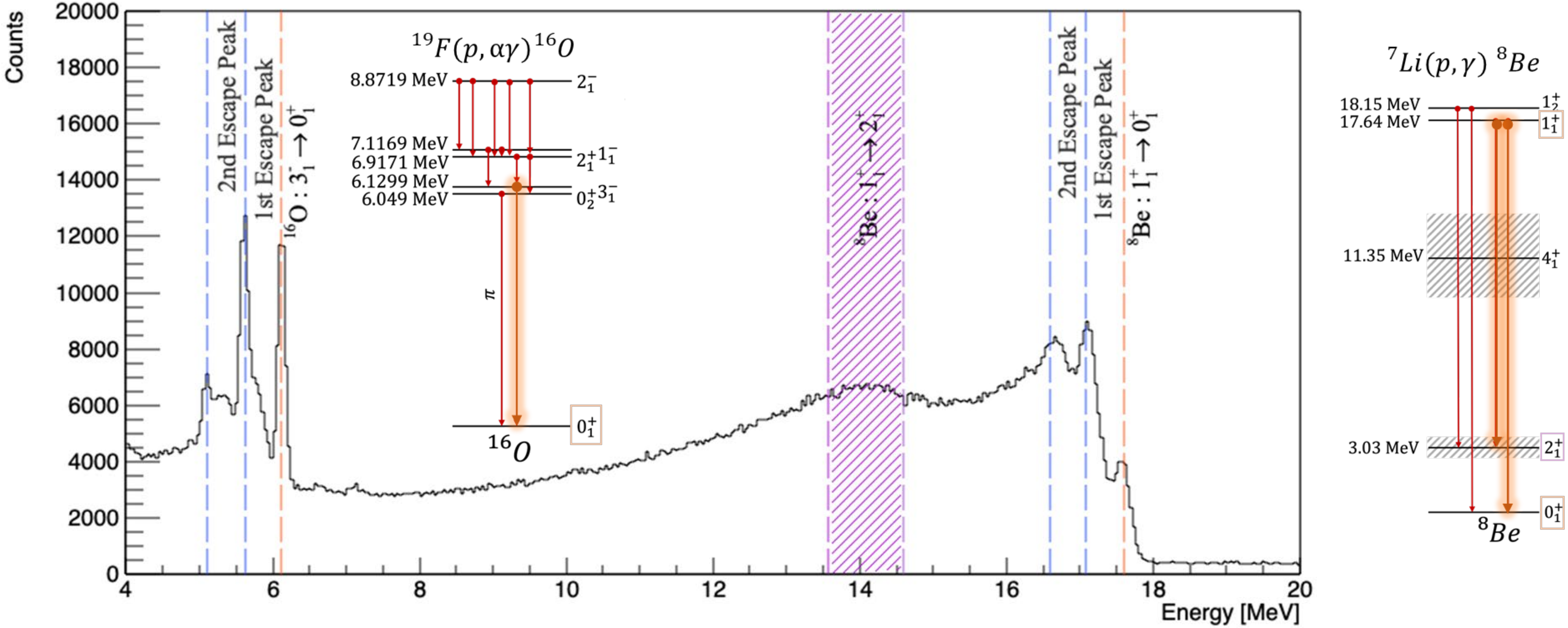
New analysis of $p + {}^{19}F$ reactions at low energies and the spectroscopy of natural-parity states in ^{20}Ne

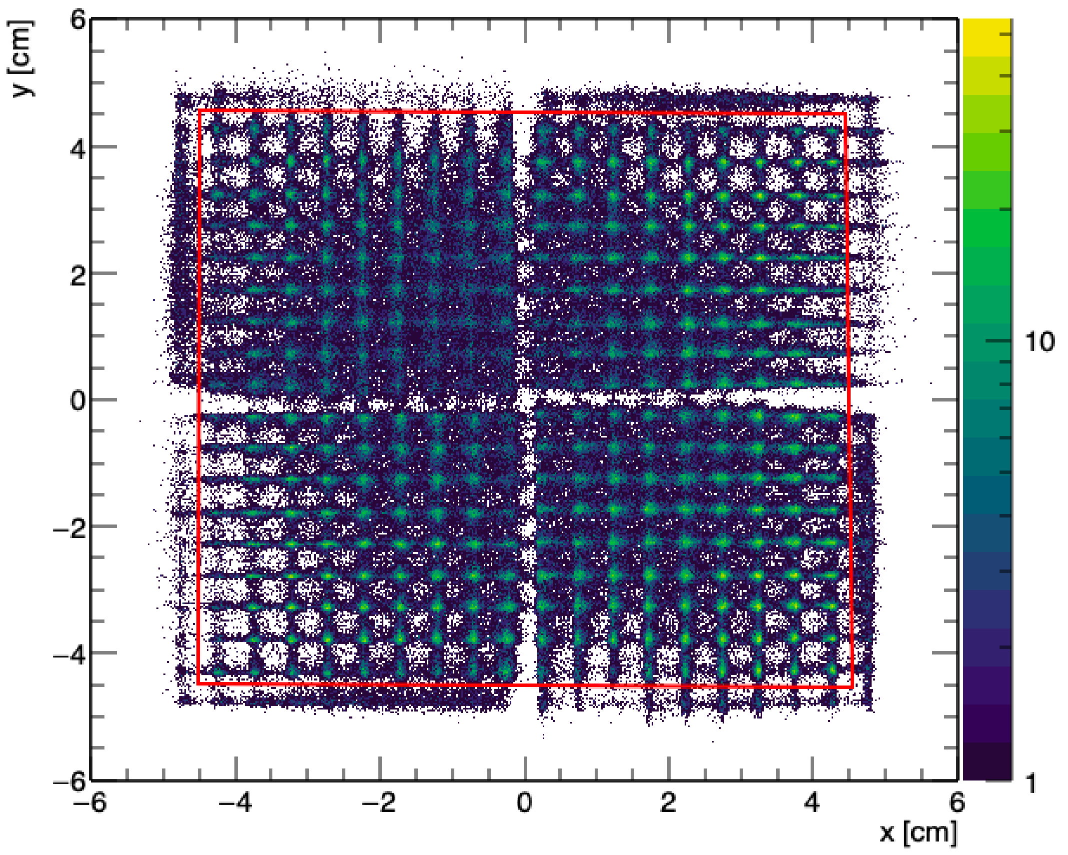
Ivano Lombardo, Daniele Dell'Aquila, Jian-Jun He, Giulio Spadaccini, and Mariano Vigilante
Phys. Rev. C **100**, 044307 – Published 10 October 2019



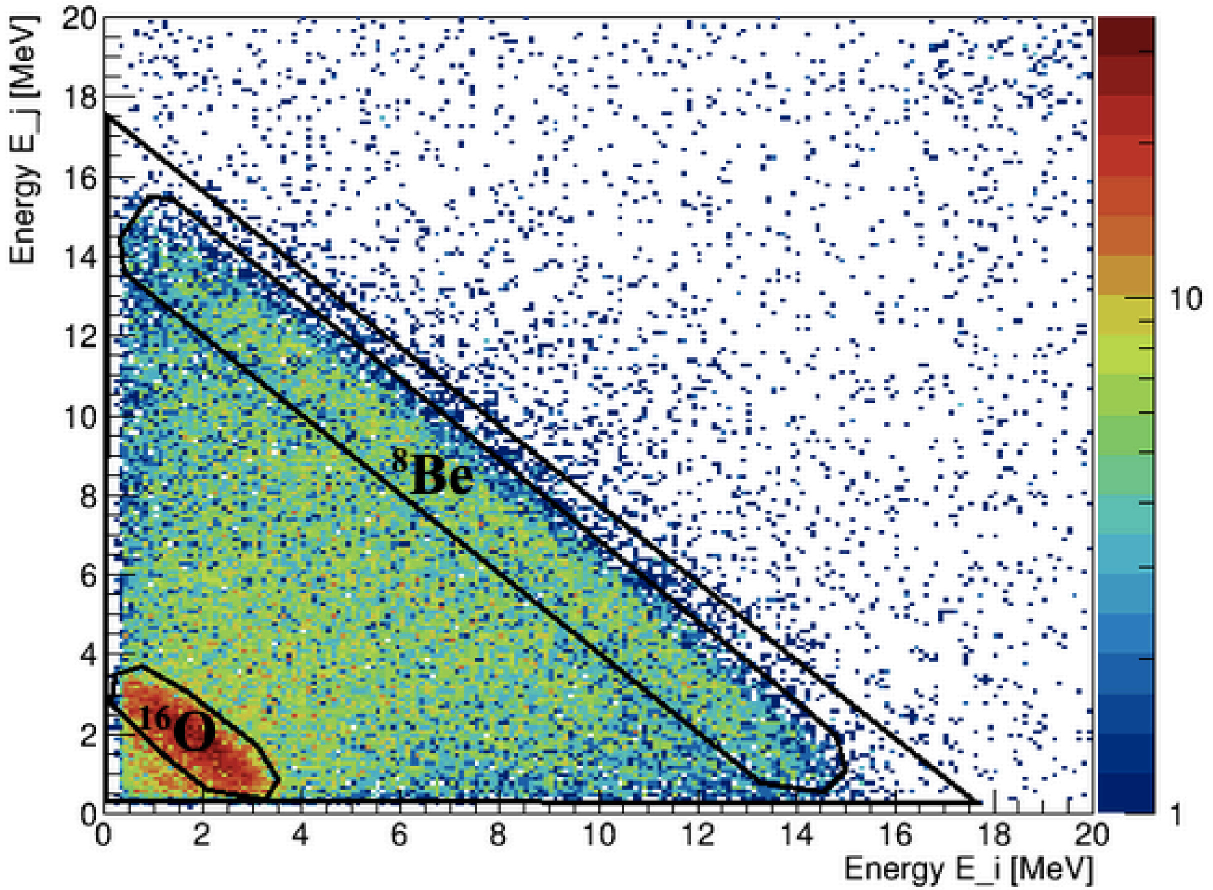


$LaBr_3$ spectrum for target monitoring and AN2000 calibration

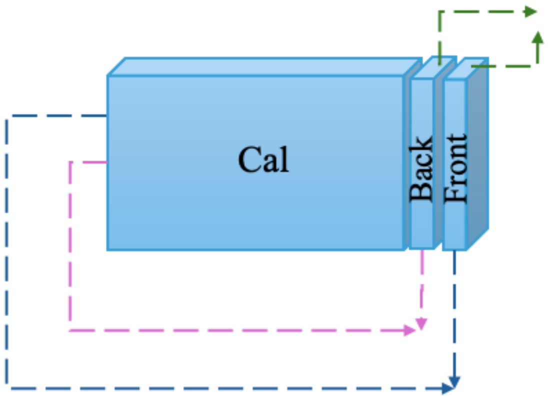


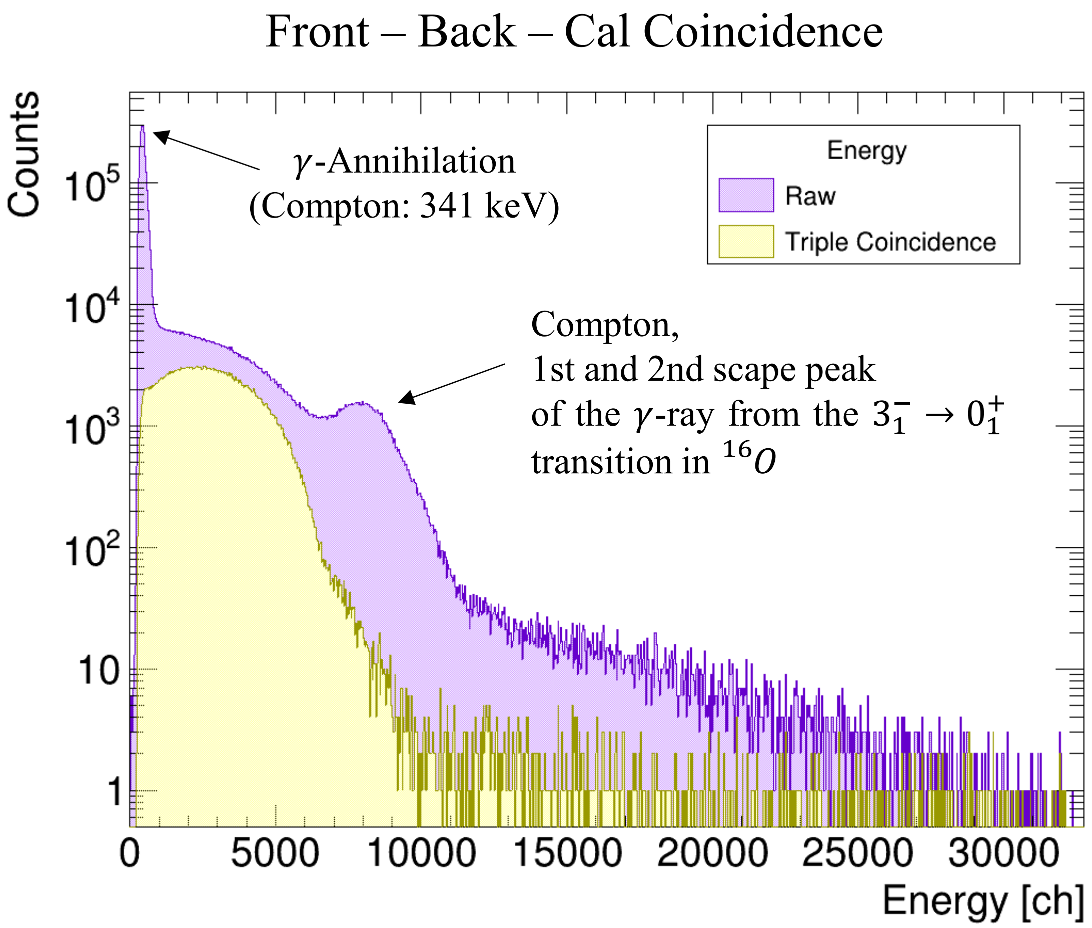


Gate to account for the low efficiency in the borders of the detector



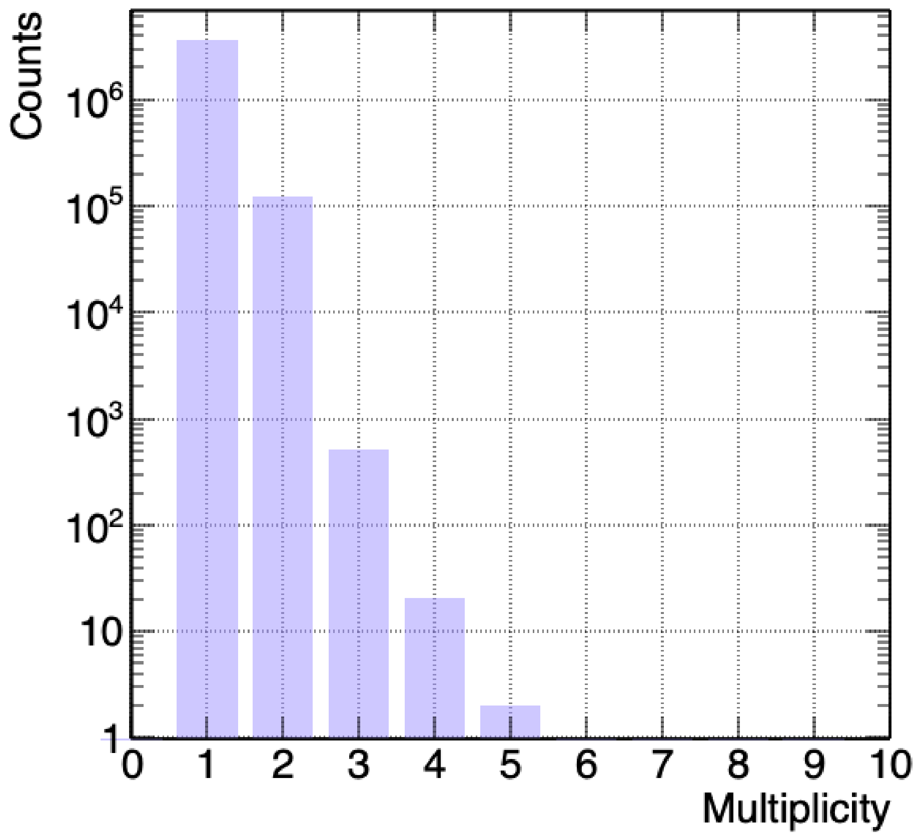
Calorimeter correlation

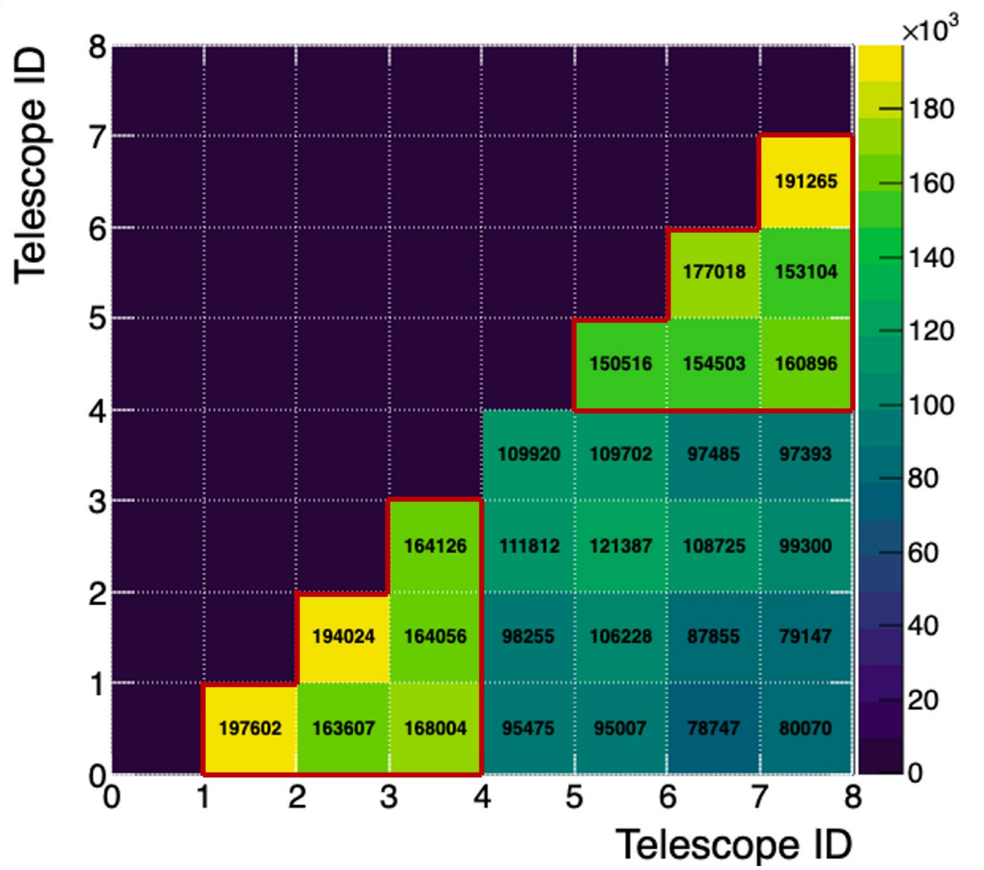




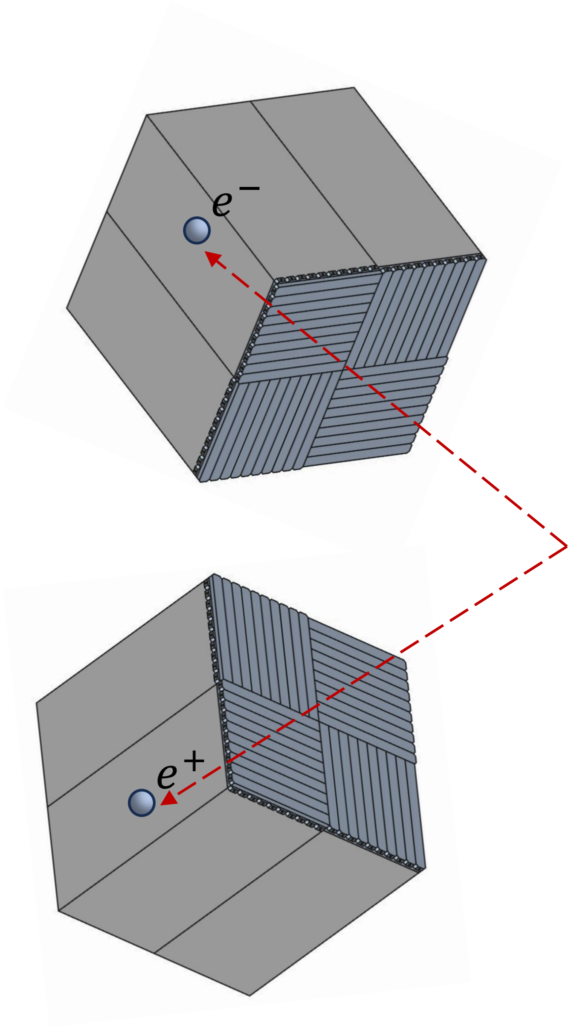
- Time coincidence of the three layers:
  - γ-rays interact mostly with only layer
  - Reduction up to 4 orders of magnitude the γ-ray background

Event multiplicity



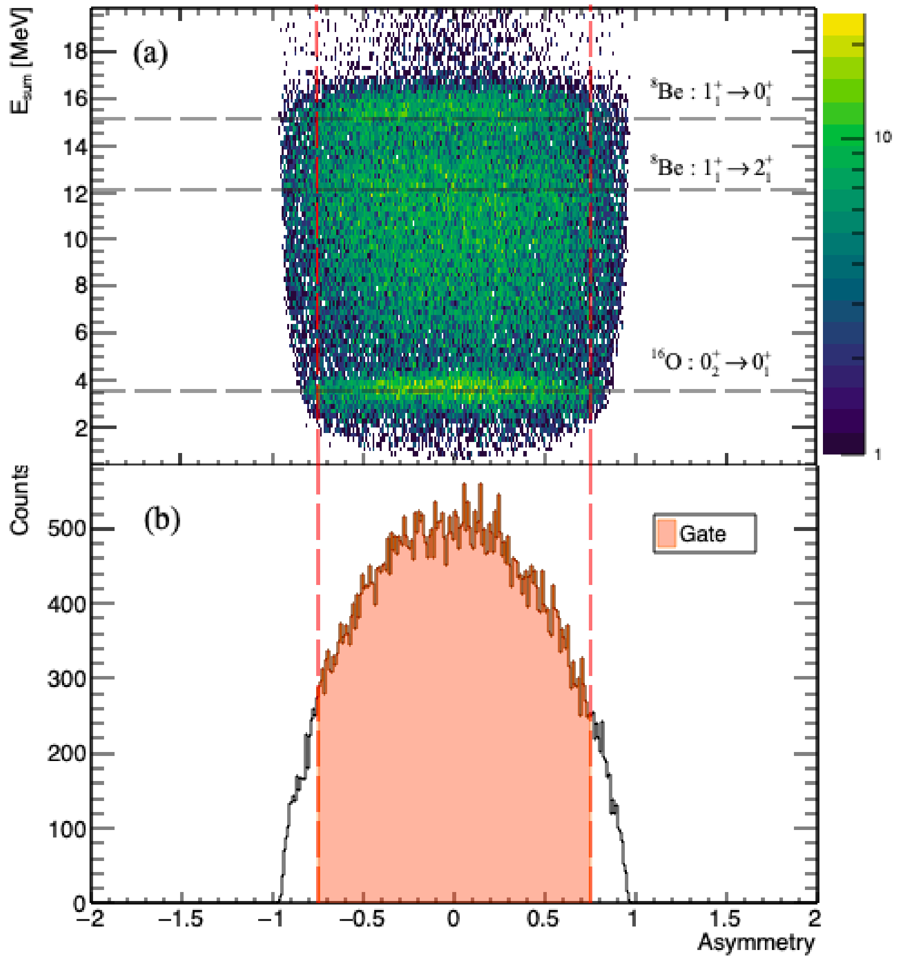


Preliminary results – energy asymmetry



$$y = \frac{E_{e^+} - E_{e^-}}{E_{e^+} + E_{e^-}}$$

$|y| < 0.5$ Atomki
$|y| < 0.75$ This work

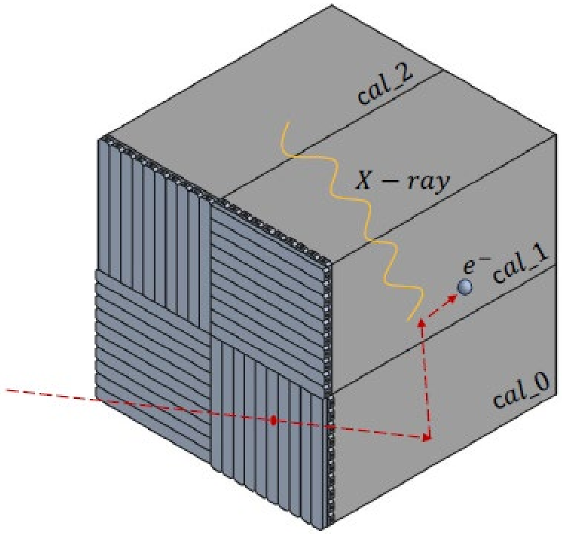


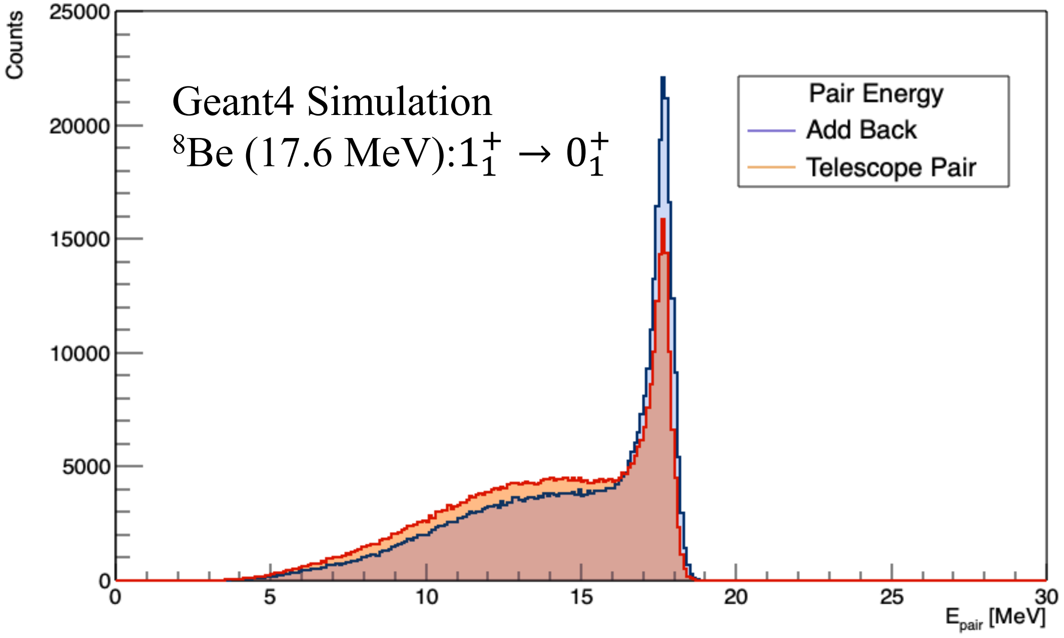
Add-back

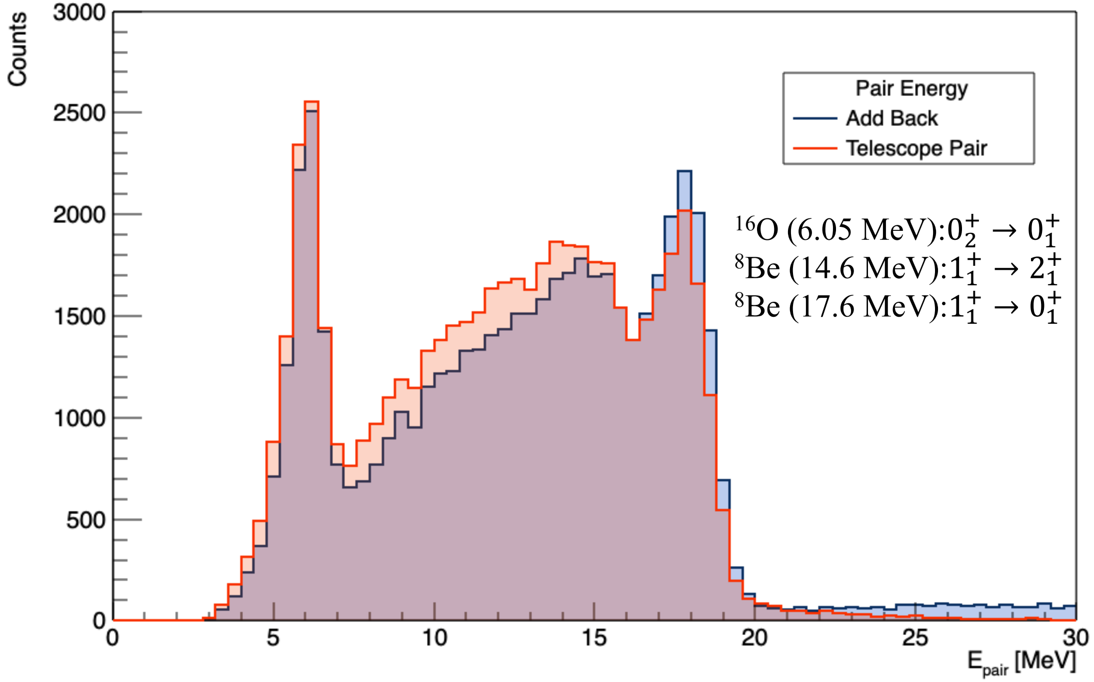
$$E_{Add-Back} = \sum_{i=0}^{3} E_{cal_i}$$

For Clover i and j in coincidence:

$$E_{pair} = E_{Add-Back}^{(i)} + E_{Add-Back}^{(j)}$$

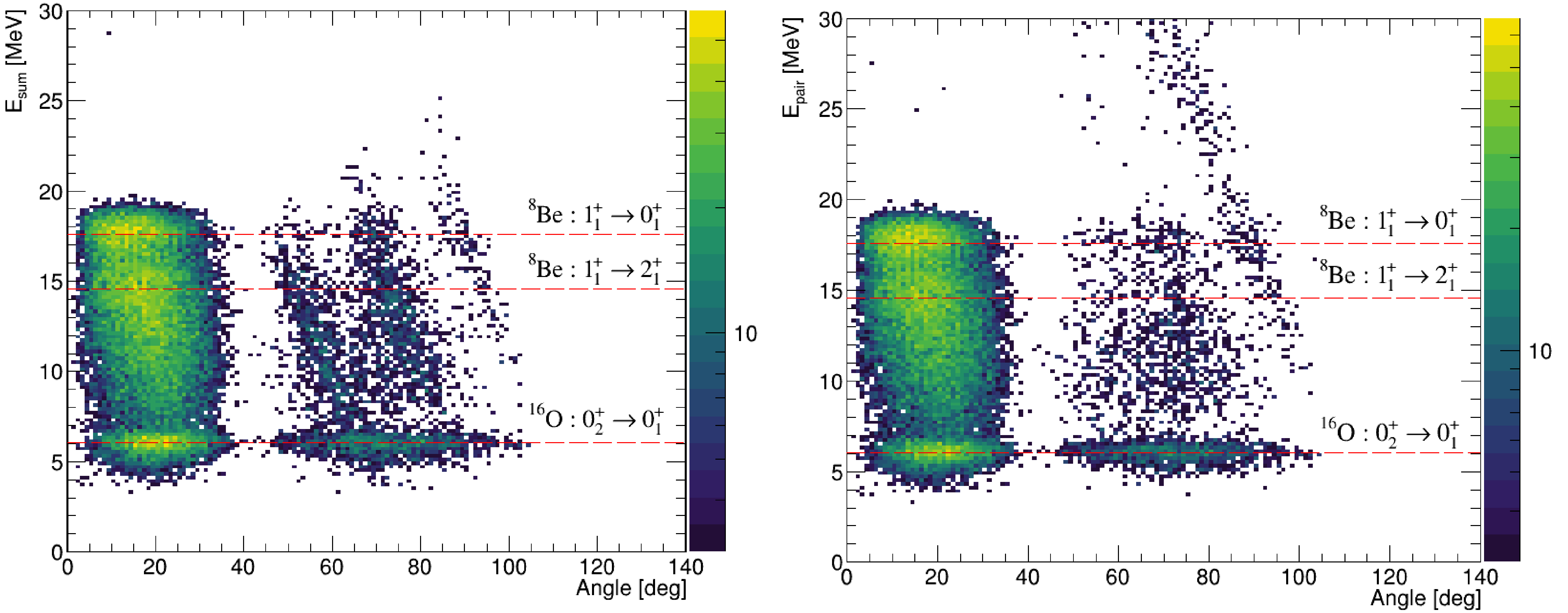






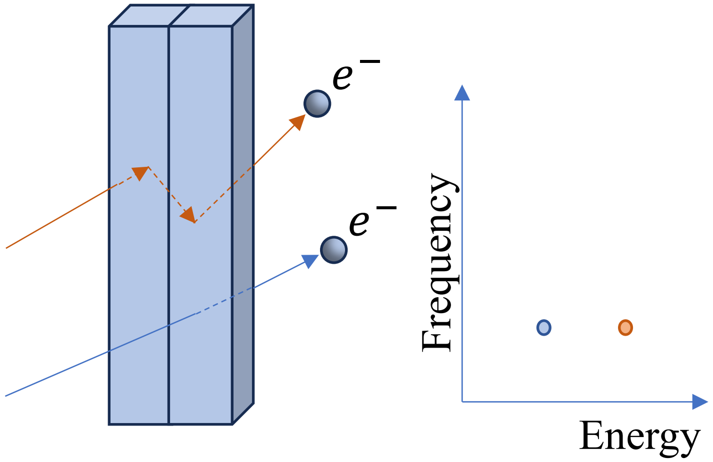
P/T (peak to total ratio) improves from 24% to 38% for a 17.6 MeV transition

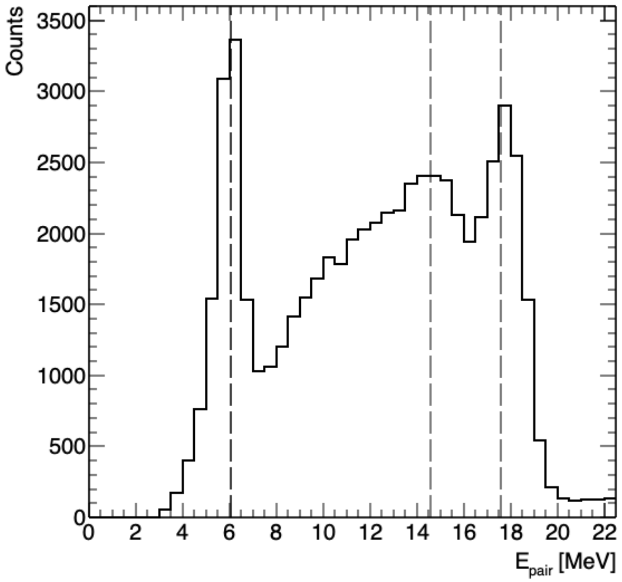
Add-back



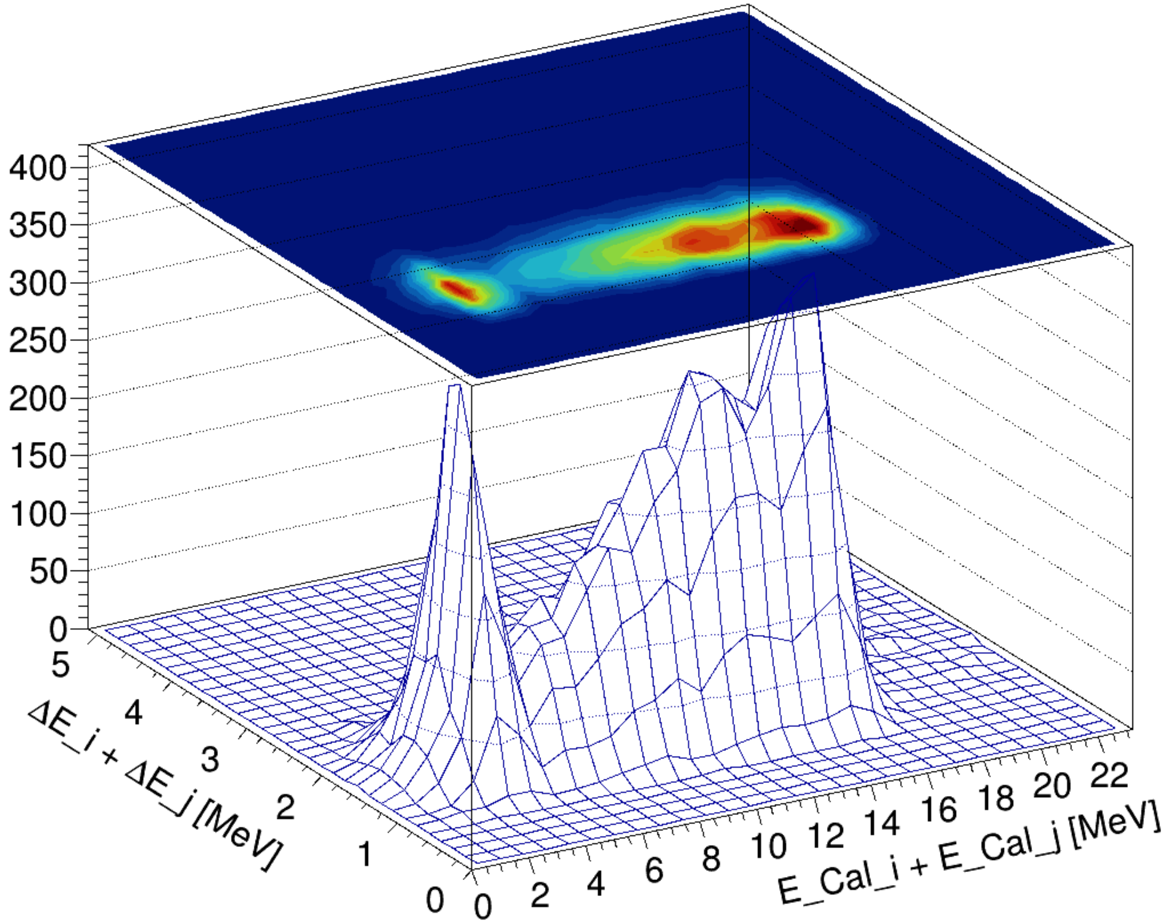
Add-back consequence: some events shifted to the high-energy region

Preliminary results – straight path selection using ΔE-E



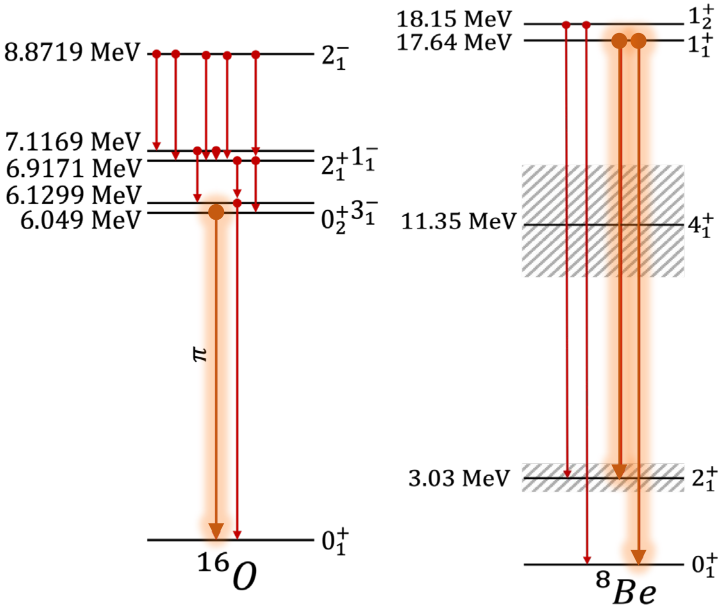


$\Delta E_{sum} - E_{sum}$

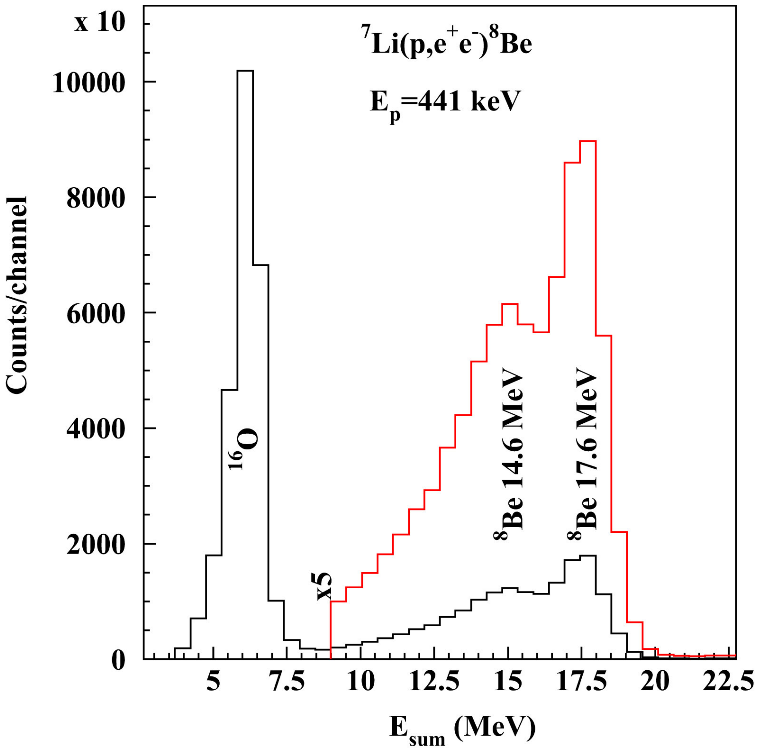


Final dE_{sum} Gate : 0.5– 2.5 MeV

Preliminary results – reconstructed energy of the leptons @ 441 keV

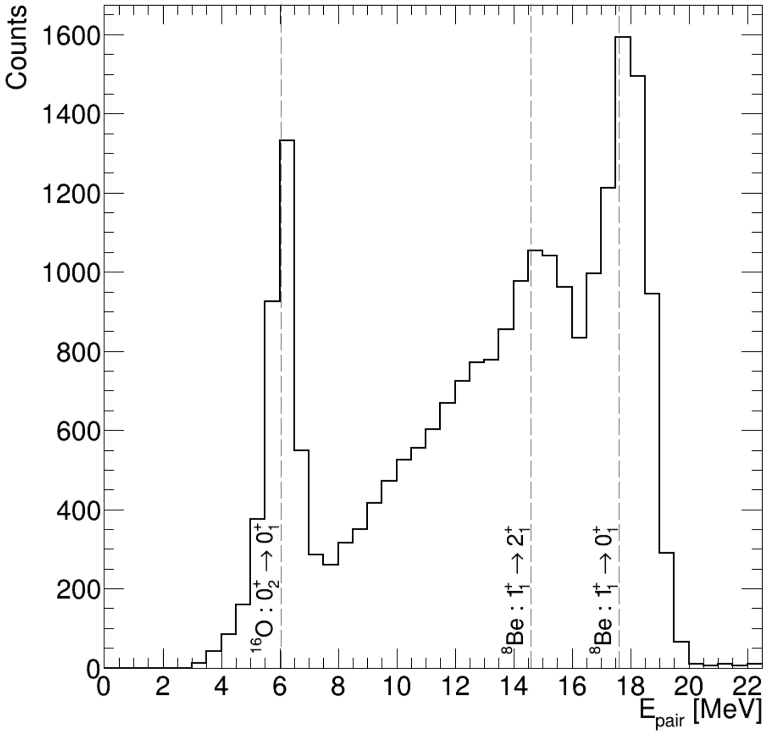


Atomki reference



$\Gamma_{17.6} = 0.8$ MeV

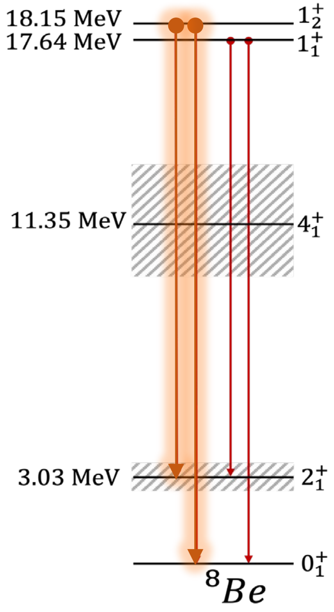
This work

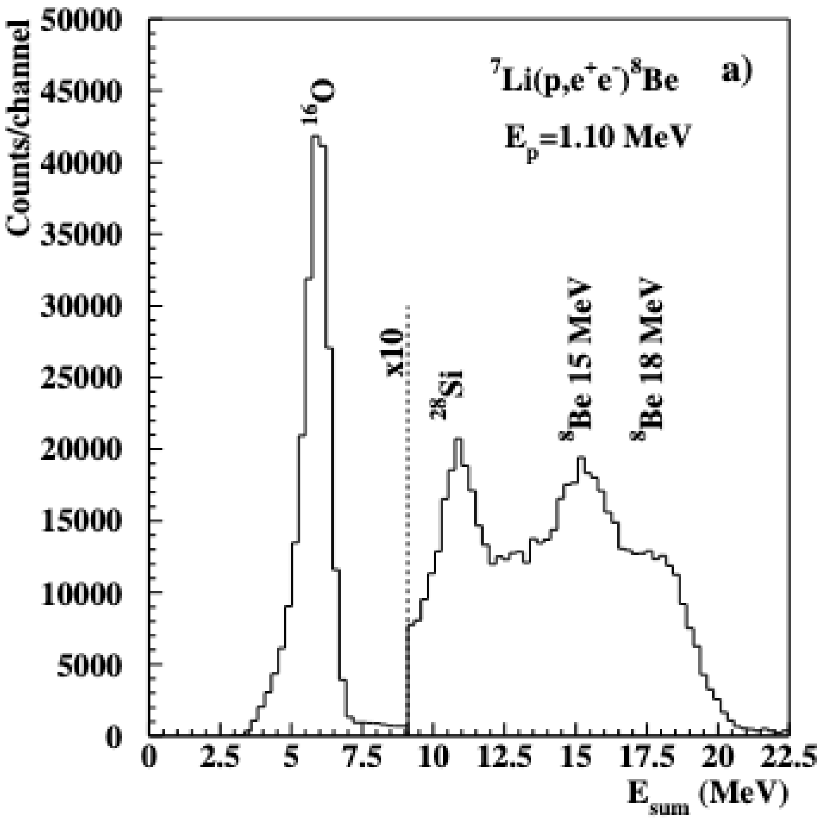


$\Gamma_{6.05} = 0.42$ MeV

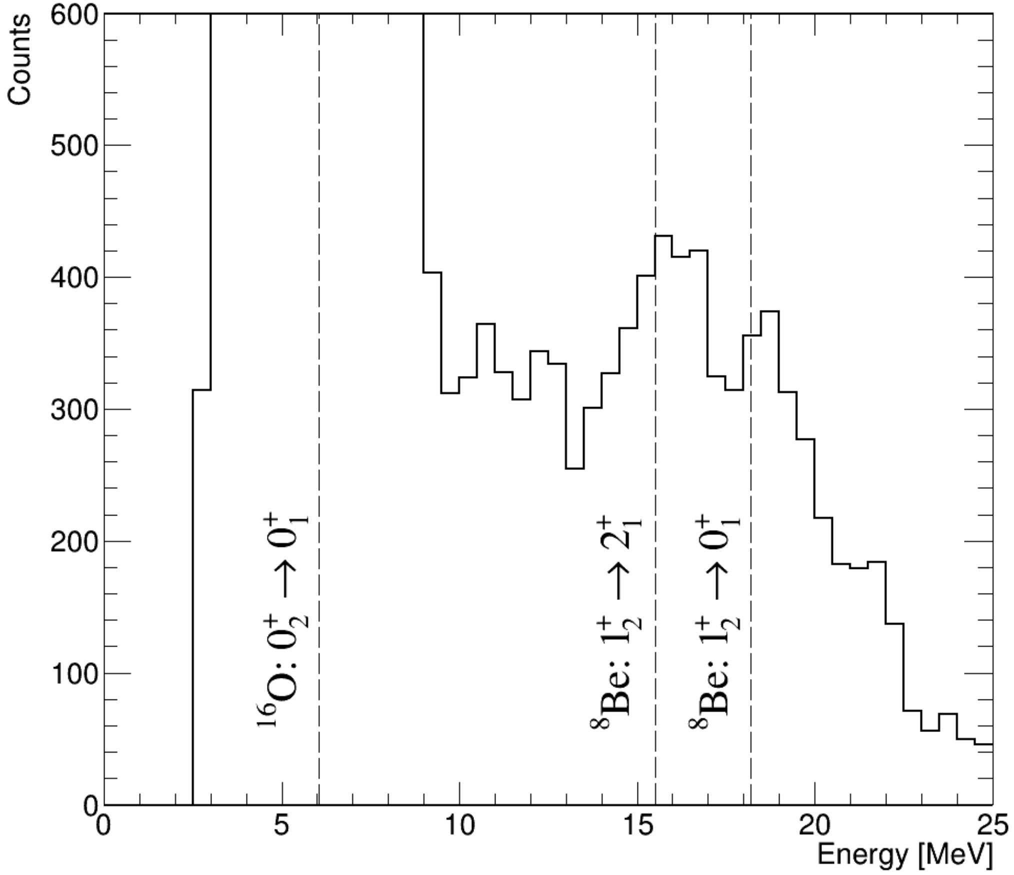
$\Gamma_{17.6} = 0.88$ MeV

Preliminary results – reconstructed energy of the leptons @ 1050 keV





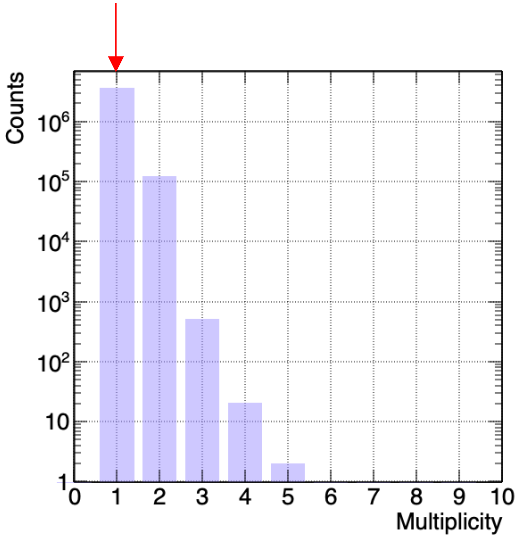
Atomki reference

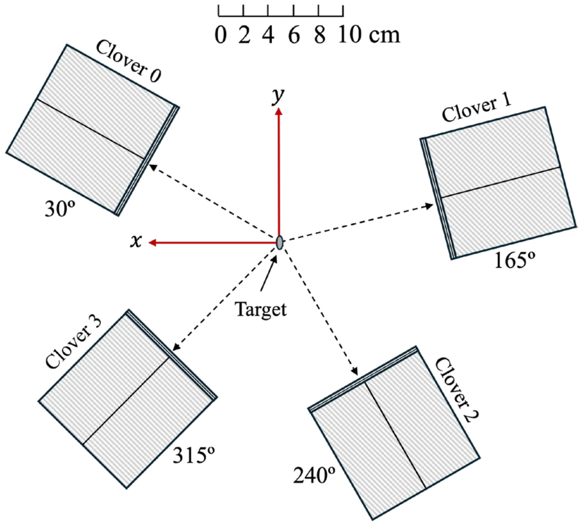


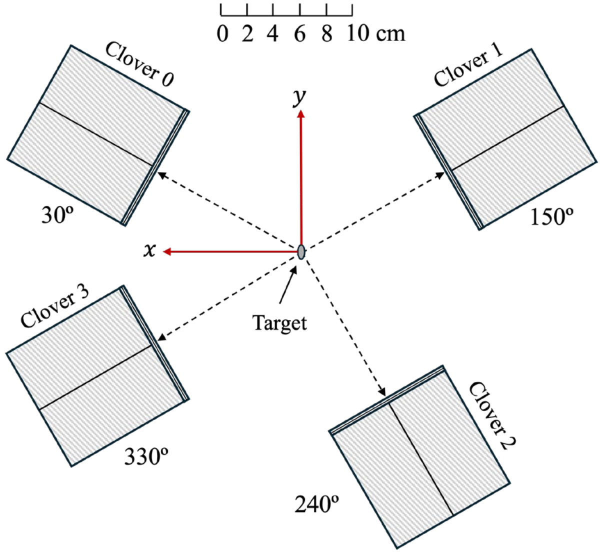
This work

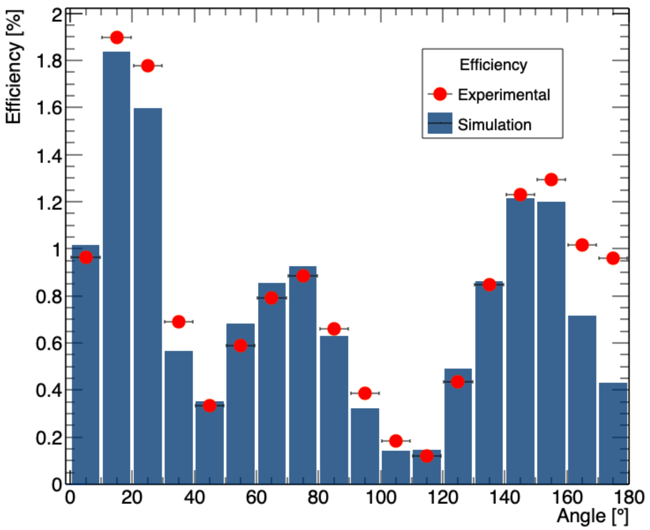
Preliminary results – efficiency estimate for the two configurations

Efficiency estimation through random correlations: pairs generated by merging two events with a multiplicity one.

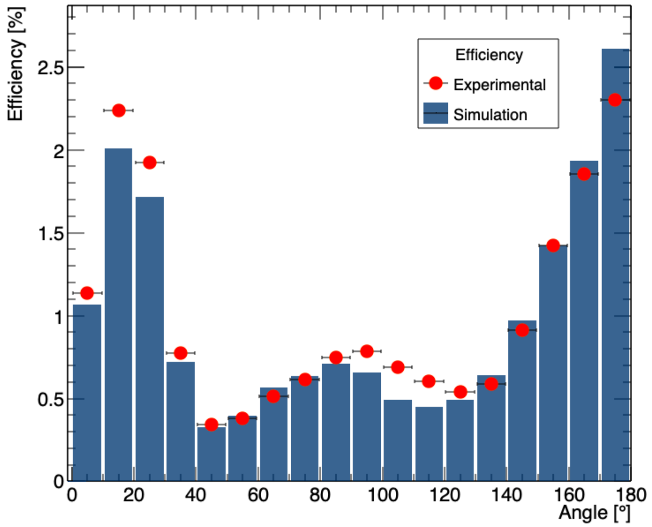






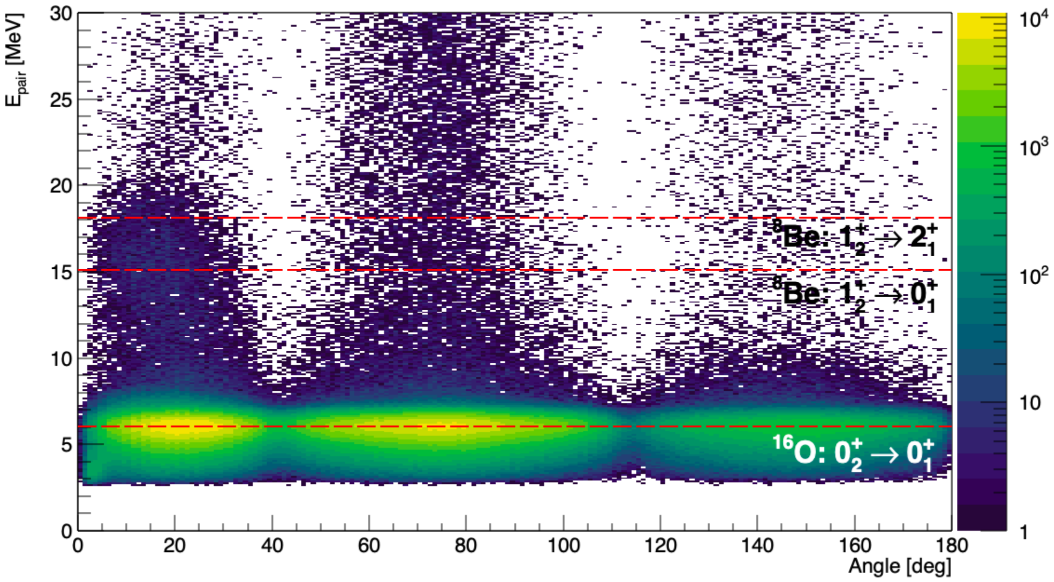


EXP I



EXP II

Energy vs Angle @ 1.03 MeV
Exp I

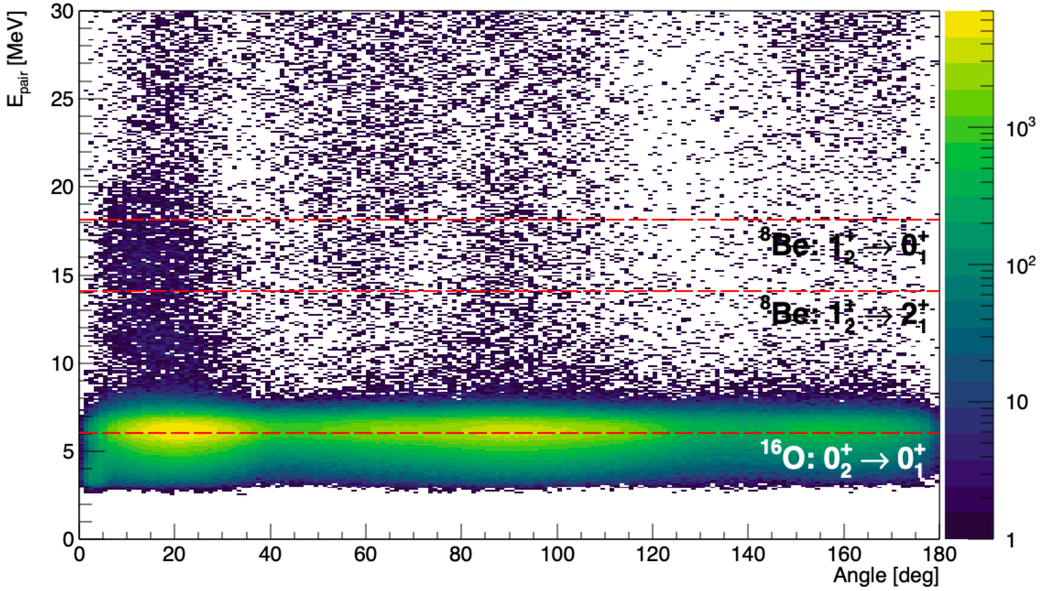


$^{8}Be: 1_2^+ \to 0$

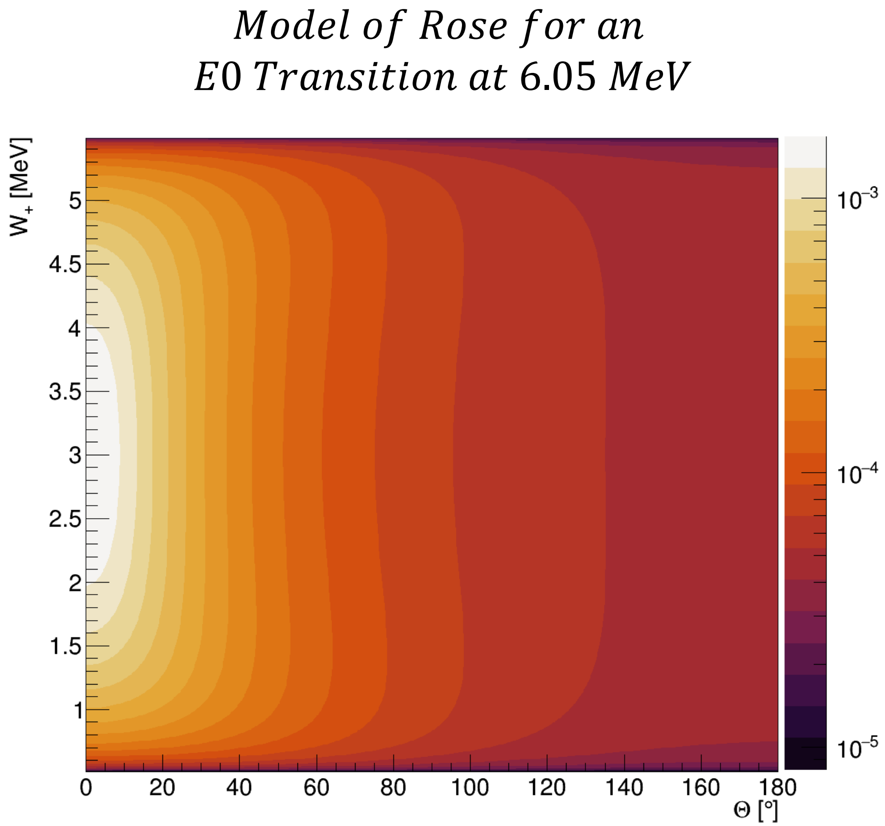
$^{8}Be: 1_2^+ \to 2_1^+$

$^{16}O: 0_2^+ \to 0_1^+$

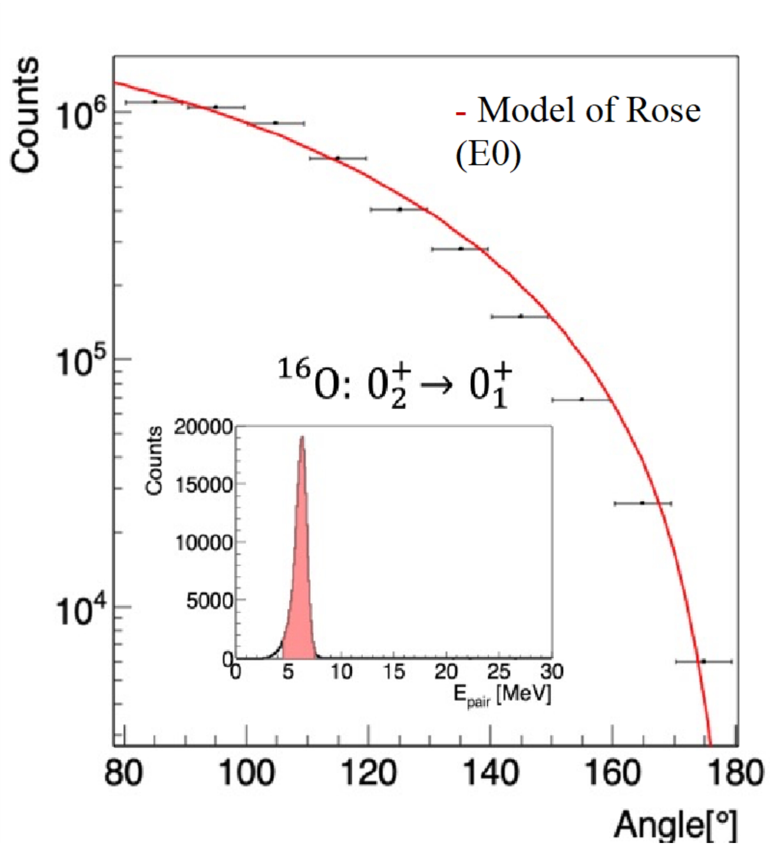
Energy vs Angle @ 1.03 MeV
Exp II



Preliminary results – E0 reference transition angular distribution (^{16}O: $0^+ \rightarrow 0^+$)



E. Rose, Phys. Rev. 76 (1949) 678.
E. Rose, Phys. Rev. 78 (1950) 184.



average discrepancy ~ 5%

Summary and conclusions

The results discussed in this talk are part of the PhD work by Benito Gongora Servin, UniFe (2025)

A new *e*+ *e*− pair spectrometer has been built to study the IPC in light nuclei:

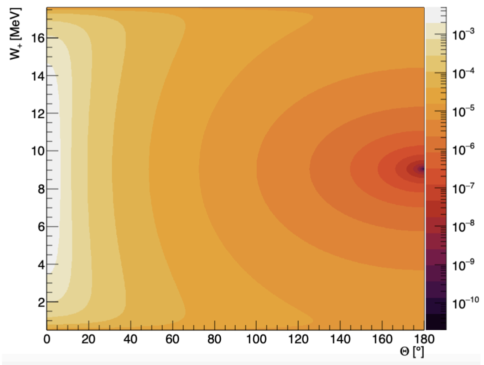
- The energy resolution ($\Gamma_{17.6}$=0.88 MeV) is comparable with the value of the spectrometer built at Atomki ($\Gamma\_{17.6}$=0.8 MeV)
- The spectrometer works in vacuum
- γ-ray suppression factor is 10^4
- Angular resolution of 2.52± 0.02 deg

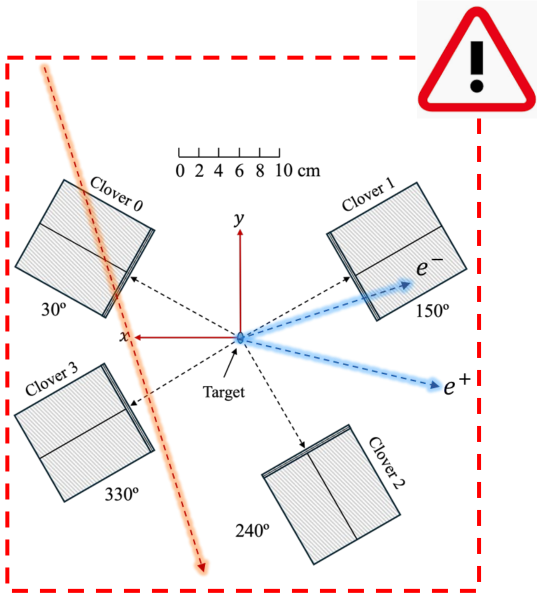
The angular correlation distribution for the E0 transition in ^{16}O was measured with an average discrepancy of 5% with respect to the model of Rose

Next steps:

- Complete the data analysis to determine the angular correlation distribution in ^{8}Be
- New runs to increase the statistics
- Add veto detectors to constrain cosmic background (?)

$M1\ Transition\ at\ 18.12\ MeV$





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